# JEFFERSON LAB


# 2000-2001 HIGHLIGHTS

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*Left:* Applied Research Center.

*Front cover:* Cropped images of Jefferson Lab.

# DIRECTOR'S STATEMENT

Jefferson Lab is one of four major basic research facilities funded in High Energy and Nuclear Physics and a premier research facility in the Southeast. The Laboratory has become not only one of the world's leading research centers offering unique capabilities for exploring and elucidating the quark structure of matter, but an unequalled resource in superconducting radiofrequency (SRF) and related accelerator technologies.

Consistent with such a forefront facility and the national investment made in its unique capabilities, Jefferson Lab is committed to pursuing excellence in science and technology, maintaining impeccable institutional management and expanding outreach efforts all in the spirit of responsible stewardship of the facility.

Jefferson Lab is at a pivotal point as a research institution looking forward, beyond executing its approved experimental program and building toward a future as scientifically exciting and compelling as its past and present. In looking toward the future, the Lab is focusing on three areas: nuclear physics (specifically hadronic physics), accelerator physics and technology, and photon science and applications.

We have delivered excellent results in each of these areas, but there is still unrealized potential that we seek to tap as we map out a scientifically and technically dynamic future for the facility. Jefferson Lab's experimental program could not be pursued anywhere else in the world, and that conveys a responsibility to continue to push the facility as the science requires working with our international user community.

Jefferson Lab is a recognized national resource in accelerator physics and related technologies. The value of this resource is evident in our involvement in the Spallation Neutron Source (SNS) project as a partner, in our participation in the R&D for the Rare Isotope Accelerator, and in planning and development of future machines that rely on our core competencies in SRF, polarized beams and energy recovering linacs to make future facilities feasible.

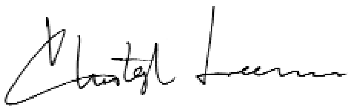
*Above:* CEBAF Center Lobby.

This unique core competency is also critical to the future of Jefferson Lab and the upgrade of its accelerator to 12 GeV to access new and compelling science. The realization of this upgrade is our highest priority because it ensures not our existence, but our vitality as a scientific institution.

This same technology has been developed into a record-breaking Free-Electron Laser that is opening new possibilities in photon science and applications. We want to continue to build on this facility and realize its full potential for basic science, industrial and defense applications.

Jefferson Lab is a vibrant, can-do organization and while the future holds significant challenges, it is critical that the nation take full advantage of Jefferson Lab's science and technology base. This includes mid-term resources that can apply to homeland defense. We want to aggressively meet our current challenges by beginning the 12 GeV upgrade to realize the compelling science that it affords. We will work within the community, the Department of Energy, and the federal government to obtain a level of operations funding that is commensurate with a world-class scientific facility. We will continue our record of excellence in institutional management and our performance as a good citizen in our community, valued as a resource in many areas.

As we look into the longer term, we must begin now to explore where the science takes us after 12 GeV. Given our scientific and technical capabilities, the support of the scientific community and the ingenuity and resourcefulness of our staff, we will map a future for Jefferson Lab that will make it a dynamic and vital resource for the Southeast and our nation for decades to come.



Christoph Leemann
Director

# OVERVIEW OF THE LAB

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is the leader in quark nuclear physics and superconducting radiofrequency (SRF) technology serving as a resource to researchers nationally and internationally. Operated by the Southeastern Universities Research Association for the U.S. Department of Energy, its principal funding source, Jefferson Lab is dedicated to performing leading-edge research in nuclear physics, superconductivity, surface science, cryogenics, computer process control applications, the physics of particle and light beams and medical imaging.

*Above:* Aerial view of the accelerator site.

The nuclear physics research complex in Newport News, Virginia, is built around the world's first large-scale superconducting electron accelerator — a complex assembly of high-tech hardware and electronics stretching through an underground tunnel almost a mile in circumference. Jefferson Lab's nuclear physics research increases our understanding of the structure of matter and the forces holding the nucleus together. The Lab serves an international user community of approximately 1,600 scientists, primarily from universities. The core technology, SRF, benefits not only Jefferson Lab, but advances research and facilities in DOE Basic Energy Sciences (Spallation Neutron Source, Next-Generation Light Source) and Nuclear Physics (Rare Isotope Accelerator). Jefferson Lab's Free-Electron Laser (FEL) is based on this core technology and has broken records for delivery of infrared light.

The Lab has important ties to the local community and emphasizes a good working relationship with local and state government. This is evident in the many ways Jefferson Lab staff serves the community including industrial advisory boards, community service organizations, and education committees. Outreach also shows in the community through BEAMS, or Becoming Enthusiastic About Math and Science, the science enrichment program for 6th through 8th graders. The Lab hosts open houses and participates in the Virginia State Fair. The public is invited to attend interesting lectures and book signings.

In this first-ever Highlights Report, the programs and staff that shape Jefferson Lab are presented so the reader may understand the directions the Lab is taking. Its plans for upgrades, the exciting physics underway here, and the dedicated staff are keeping the facility at the forefront of research.

*SURA is a consortium of southeastern universities that manage and operate Jefferson Lab under contract for the U. S. Department of Energy. Dr. Jerry Draayer is the president of SURA.*

**Southeastern Universities Research Association**

**Alabama**
- The University of Alabama
- The University of Alabama at Birmingham
- The University of Alabama in Huntsville
- Auburn University

**Arkansas**
- The University of Arkansas

**Delaware**
- University of Delaware

**District of Columbia**
- The American University
- The Catholic University of America
- The George Washington University
- Georgetown University

**Florida**
- The University of Central Florida
- University of Florida
- University of Miami
- Florida Atlantic University
- Florida Institute of Technology
- Florida International University
- Florida State University
- University of South Florida

**Georgia**
- Clark Atlanta University
- Emory University
- The University of Georgia
- Georgia Institute of Technology
- Georgia State University

**Kentucky**
- University of Kentucky

**Louisiana**
- The University of Louisiana at Lafayette
- Louisiana State University
- Louisiana Tech University
- University of New Orleans
- Tulane University

**Maryland**
- University of Maryland

**Mississippi**
- Mississippi State University

**North Carolina**
- Duke University
- The University of North Carolina at Chapel Hill
- North Carolina State University

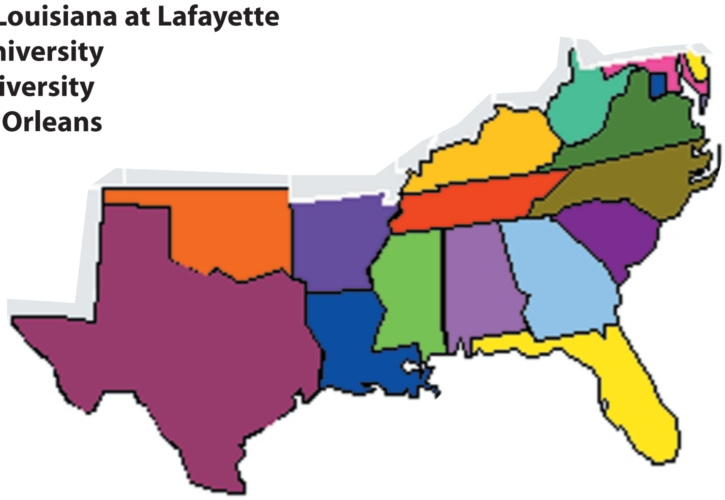
**South Carolina**
- Clemson University
- University of South Carolina

**Tennessee**
- The University of Tennessee
- Vanderbilt University

**Texas**
- The University of Houston
- Texas A&M University

**Virginia**
- Christopher Newport University
- George Mason University
- Hampton University
- James Madison University
- Norfolk State University
- Old Dominion University
- University of Richmond
- University of Virginia
- Virginia Commonwealth University
- Virginia Polytechnic Institute and State Univ.
- Virginia State University
- College of William and Mary

**West Virginia**
- West Virginia University



# SCIENTIFIC EXCELLENCE

## BENEFITTING FROM BASIC SCIENCE

Decades of basic scientific progress can be easily held in the palm of one hand. One thin, plastic-coated silvery compact disc required basic physics research in electronics, semiconductor growth, thin metallic films and lasers. Far from being an arcane pursuit of knowledge for its own sake, the study of atoms and their constituents have led and are leading to new procedures and devices that otherwise would prove impossible to create or design.

*Above:* Physics research has enabled small hand-held computers.

Basic research undergirds economic development. The private sector focuses on short-term return on investment. The United States government funds universities and federal laboratories that contribute to the future knowledge, technological and economic base for the nation.

Fueling the Information Age revolution was the invention of the semiconductor transistor in 1947 — itself based on physics research. The microprocessor is now ubiquitous, found in everything from telephones to televisions, cars to, sometimes, cereal boxes.

Consumer electronics make up an increasing percentage of the U.S. gross domestic product, employ millions of Americans and have created products and services unthinkable even two decades ago.

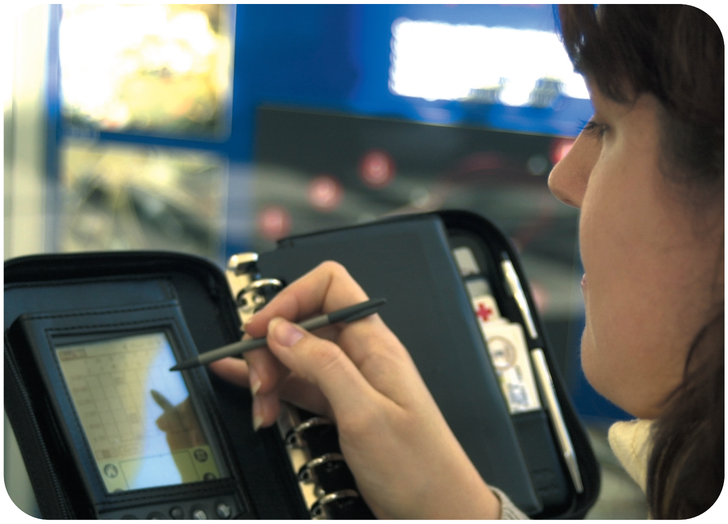
Physics research into heat transfer and the subsequent development of thin films, plasma sources, vacuum technology, optics and new materials has directly led to energy-efficient window coatings, insulating layers, and "smart" windows that grow dark or reflecting in sunny weather. Applied plasma physics and microwave technology has also resulted in the development of more powerful, durable light bulbs that use up to two-thirds less electricity than standard bulbs. Nuclear physics research has lead to many beneficial medical spinoffs such as positron emission tomography and nuclear medical imaging.

It takes years to accumulate the experience, personnel, equipment and facilities necessary to conduct first-class research. Consider the case of Jefferson Lab. Counting from the initial discussions, it took almost two decades to identify the funding, get it built, get it commissioned and then transition into smooth operation. If we don't make similar commitments to long-term investment in basic research, there will be an erosion in the knowledge necessary to create new goods and services and keep a healthy economy.

At Jefferson Lab, the basic mission of studying quarks has already resulted in practical benefit. Researchers have created a new class of ultra-sensitive medical imagers derived from the Lab's detector technology that was originally intended to track subatomic particles in flight. This new generation of portable, lightweight instrumentation is expected to help doctors identify small, hard-to-detect cancer cells, making possible preventative treatments and improved recovery from surgery.

*Above:* Microprocessors and radiowaves enable cell-phone technology.


*Above and right:* Because of advances in solid state physics, laptop computers and hand held computers can now communicate wirelessly.



In addition, the Lab's FEL program is a nuclear physics spin-off and is exploring means of producing high-quality coatings and thin films for electronics and microcomponents, as well as the laser production of a new class of high-strength materials called carbon nanotubes. An FEL also has the potential to substantially reduce the cost of photovoltaic panels by boosting their light-gathering capacity. Other FEL applications are also possible, including treatment of packaging to make it more resistant to microbes and food spoilage. The FEL could be used by companies that forge, coat, treat and clean metals of all kinds; businesses that micromachine materials and parts; and manufacturers who fashion semiconductors.

The value of basic science isn't always immediately apparent. What is obvious is the economic impact: Return on investment is virtually guaranteed in the long run. Some estimates peg that rate of return as high as 50%. And that doesn't include the incalculable return on unanticipated inventions that can achieve that which was previously undoable.

Without basic research in physics, we wouldn't have computers, lasers or the Internet – three of the most far-reaching inventions of the 20th century. It's sometimes hard to explain the value of understanding the forces that hold together the nucleus of an atom. Last century it was obvious how nuclear energies could be used: as a weapon, as a power source, as a source of medical instrumentation. What we're doing now is well beyond the realm of those applications. In the years ahead, basic science will continue to make positive contributions to the nation.

# EXPERIMENTS SHOW SIGNIFICANT PROGRESS IN ALL THREE HALLS

This past year, experimenters have made significant progress in nuclear physics research in all three of Jefferson Lab's experimental halls. The investigations are fulfilling the Lab's mission of enhancing our insight into the structure of matter. Quarks, together with the force-carrying particles known as gluons that direct quark interactions and bind the quarks within protons and neutrons, are the basic particles believed to comprise all of nuclear matter.

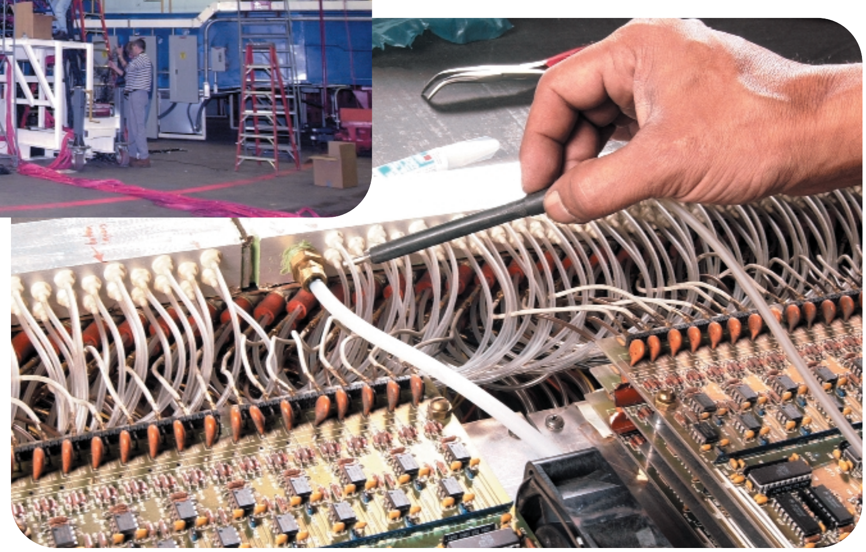
Researchers continue to credit the quality and power of the JLab continuous electron beam for their ability to peer ever more deeply into atomic nuclei. Within the next five years, a planned energy doubling, from the current six billion electron volts, or 6 GeV, to 12 GeV should further enhance our research capabilities.

"We have certainly made progress toward completing the signature measurements the Lab was built to carry out," says Larry Cardman, associate director in JLab's Physics Division. "Broadly, we've made tremendous progress on all the experimental programs. We're getting really good science done and results are coming out in a steady stream."

What follows is a brief summation of notable nuclear physics research that has occurred over the last year.

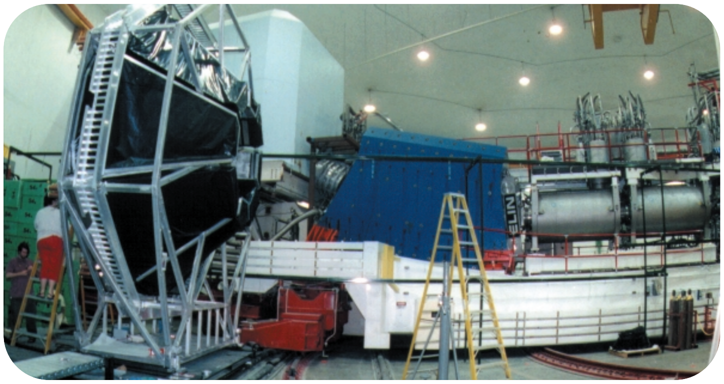
A landmark experiment in **Hall A** has mapped the distribution of electric charge and magnetism within the proton, a minuscule object about one billionth of one millionth of a meter in diameter. Previous experiments have provided a clear picture for the distribution of magnetization, showing that it peaks in the center of the proton and falls off rapidly with distance from the center. The new data show that the electric charge density is significantly lower than the magnetization density in the proton's center, and may be unexpectedly dense further out from the center. These data provide a fascinating challenge for theorists attempting to explain the structure of the proton in terms of its fundamental quark and gluon constituents. "What we've done," Cardman points out, "is to lay on the table a ruler that can be used to validate theories of the nucleon. It's a gold-plated test."

The experiment was made possible by the ability of the JLab accelerator to produce an intense



*Above:* Hall A and a portion of its massive magnets used to direct particles into detectors for analysis.

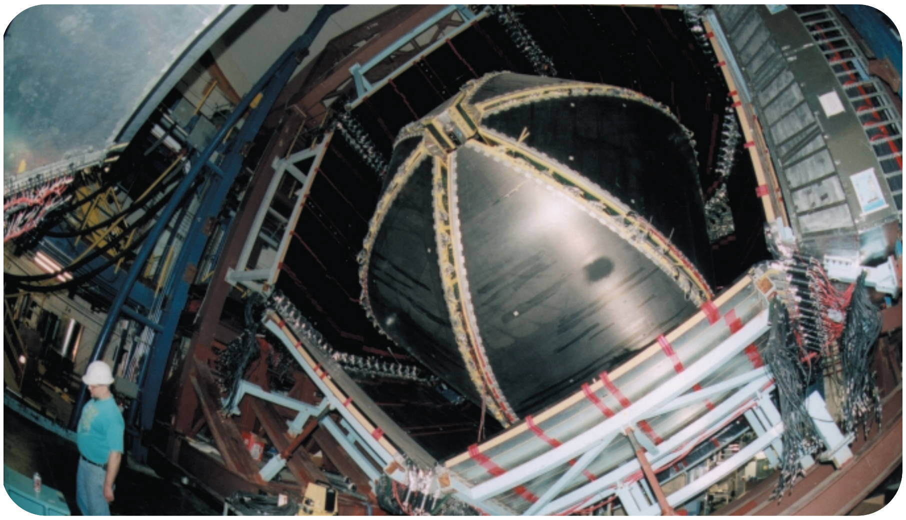
*Right:* Electronics in detectors in all three halls capture data that lead physicists to conclusions about the quark structure of matter.



*Above:* The frame for the G0 spectrometer in Hall C with wedge-shaped particle detectors installed.

*Left:* William and Mary post doctoral research associate Julie Roche (left) and graduate student Jeff Secrest build scintillators to detect protons for an experiment planned for Hall C called G0. G0 will study the contribution of strange quarks to the proton and will run in Hall C in late 2002.

*Below:* Hall B runs multiple experiments simultaneously and collects up to a terabyte of data a day.



beam of polarized electrons (polarization puts electrons into identical magnetic alignment, standardizing the mathematically expressed quantity known as "spin"), permitting unprecedented, detailed examination of proton structure. Using varying beam energies, from 4 to 6 GeV, researchers were able to chart the ratio of the electric to the magnetic distribution over a wider range than was previously possible.

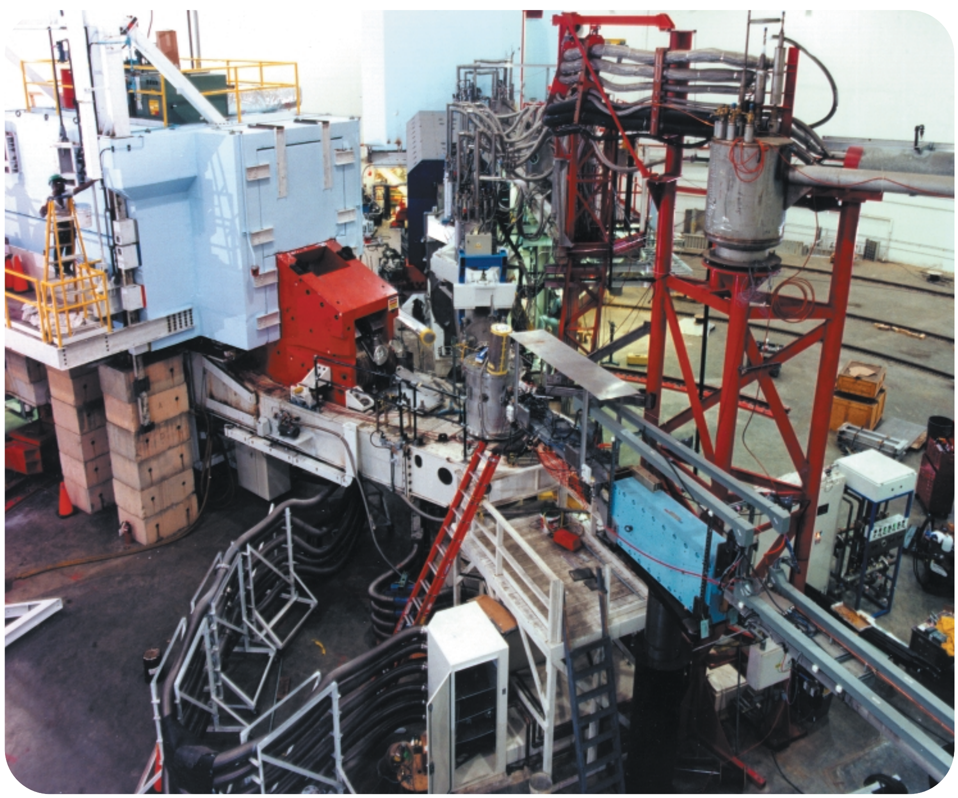
A complementary **Hall C** experiment that also used JLab's polarized electron beam has provided similar information on the distribution of charge in the neutron. Although the total charge of the neutron is zero, physicists have known for many years that the neutron had positive charge near the center and negative charge near its outer edge. The Hall C experimenters have created the equivalent of a sophisticated subatomic map that shows us exactly how the positive and negative charges are distributed within the neutron. These data are highly sensitive to theories of the neutron.

The past year also saw the first

publications from experiments using the CLAS detector in **Hall B**. CLAS can be used to study complex reactions that often occur when large, carefully measured amounts of energy and momentum are deposited in protons, neutrons, or complex nuclei. By studying how these objects break apart when struck, we learn about their internal structure. One of the first experiments studied the simplest excitation in the proton, which is fairly accurately described as "flipping the spin" of one of its quarks. By observing differences from this simple description, the CLAS experiment has further confirmed the inference from the proton charge distribution measurement that quark and gluon theories of the proton will have to incorporate relativistic dynamics to be successful.

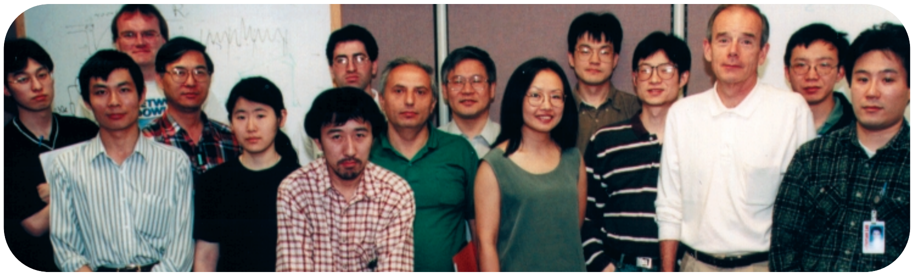
In a series of experiments carried out in both Hall A and Hall C, researchers have collected key new data on another important question in nuclear physics — Where is the boundary between classical nuclear physics and the underlying, more fundamental, quark and gluon description of nuclei? "Classical nuclear physics, which considers the proton and the neutron as fundamental objects and characterizes their interaction through the exchange of mesons, is a theory that's worked pretty well over the past 50 years," Cardman asserts. "It can make good predictions about atomic nuclei. Important JLab

*Above:* Scientists monitor data collected 24 hours per day during an experimental run.



*Above:* Hall C is a multipurpose hall where different experimental equipment can be assembled, used, and disassembled as the need arises.

experiments carried out two years ago showed that it works well down to distances of about one half of a femtometer (about one half the size of a proton). But conventional theory only goes so far, and then you have to take into account the underlying quark and gluon structure."

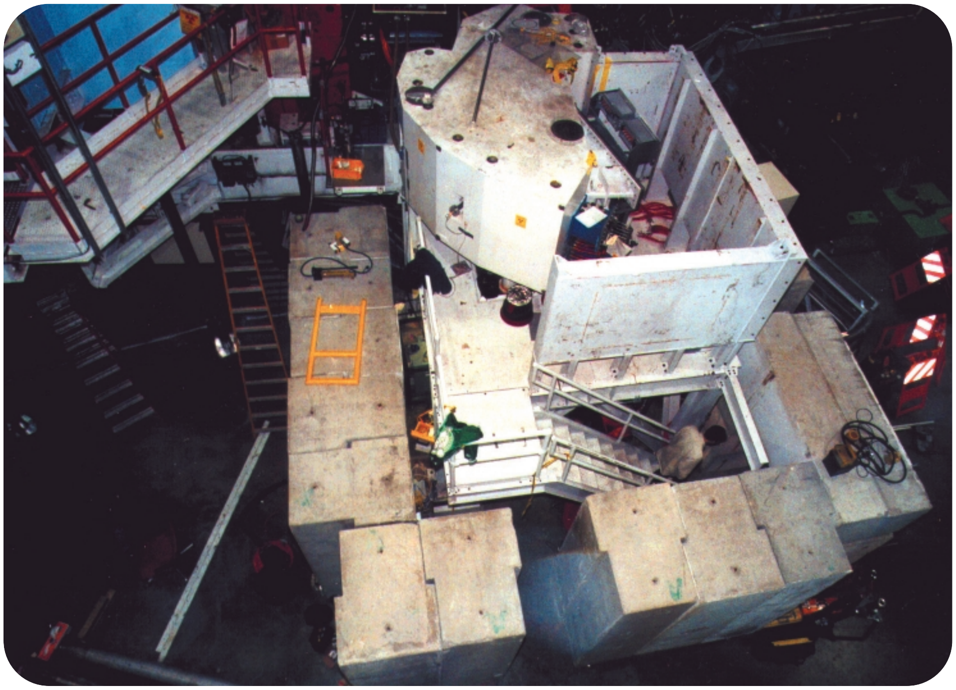


*Editor's note: A more detailed description of one of these experiments can be found on page 10.*

A very different experiment in Hall C demonstrated that researchers can use the JLab accelerator to investigate hypernuclei. In a hypernucleus one of the protons is replaced by a lambda particle. Because the lambda is different from the proton, it acts as an impurity and can sample aspects of nuclear structure not accessible to experiments done with ordinary reactions. Before the JLab experiment, substantial doubt existed whether the Lab or any other facility could effectively build the equipment required to create and examine hypernuclei using electron beams, and then collect data at the high rates necessary. This proof-of-concept research demonstrates that the Lab will be able to conduct a new class of experiments previously thought extremely difficult, if not impossible. A major new instrument to pursue this physics at JLab is being built under the leadership of a group from Japan.

Very broadly, the JLab nuclear physics program has made remarkable progress this past year toward unraveling some of nature's most closely guarded secrets. "One of the deep puzzles we deal with here is why is it that neutrons and protons act as if they are fundamental particles, or nearly so," Cardman posits. "We know that they are made up of quarks and gluons, but we don't know how. That's why we do what we do at the Lab: study the basic structure of protons, neutrons, and nuclei to provide theorists with the insights necessary to solve this problem and with data that can test their theories carefully."

*Editor's note: Technical details on experiments and data are available on the enclosed CD.*



*Above:* U.S. and international collaborators met to analyze data captured during the successful run of experiment E89-009. The physicists are studying hyperons — three-quark structures nearly identical to that of protons and neutrons, with one significant difference: the presence of a strange quark.

*Left:* Experiment E89-009 used a 60-ton Enge Split-pole Spectrometer (analysis magnet) with strip detectors to study hyperon-containing nuclei, generally referred to as hypernuclei. A shield house was built around the spectrometer to protect sensitive equipment during the experiment's run.

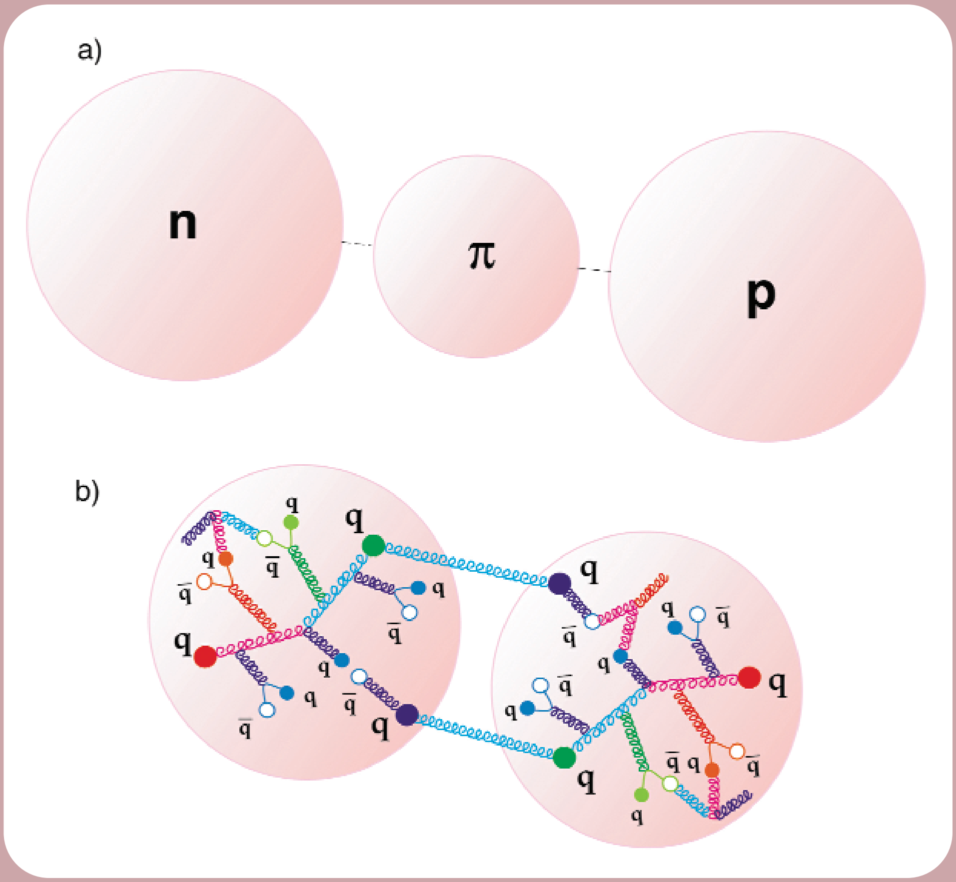
# EVIDENCE FOR THE ONSET OF QUARK EFFECTS

*American Institute of Physics*

Evidence for the onset of quark effects in a nuclear reaction has been observed for the first time. When a particle strikes a nucleus at low energies, one can effectively describe the resulting behavior of the nucleus in terms of its constituent nucleons (neutrons and protons) and the mesons which hold them together. At low energies, one does not have to worry about the fact that each nucleon is itself made of three quarks held together by gluons (Illustration a).

When a particle strikes a nucleus at high energies, however, it penetrates the nucleus so deeply that this "effective theory" breaks down, and one must describe the nuclear action in terms of only quarks and gluons (Illustration b). There is a middle ground, alas, where neither descriptive picture can do the job completely.

Just as urbanologists strive to locate where a city truly ends and its suburbs begin, physicists wish to find the boundary at which nucleon-based descriptions give way to quark-based ones. Towards this end, researchers study the behavior of the deuteron, the simplest nucleus, made of a proton and a neutron bound together.




*Above: Graphic adapted from "Nuclear Physics, The Core of Matter, the Fuel of Stars," National Research Council, 1999.*

In experiments at Jefferson Lab, a multi-institutional collaboration fired a high-energy electron beam at a copper target, which decelerated the electrons, creating high-energy photons as a result. In a process known as "photodisintegration," the photons impinged upon a deuterium target, and broke apart deuterons into their constituent protons and neutrons.

The researchers then studied the properties of protons emitted at various angles from the collision. When the emitted proton has at least 1 GeV/c of momentum perpendicular (transverse) to the incoming beam, the data were best described by quark-counting rules, which take into account the behavior of individual quarks.

The transverse momentum translates to an interaction with the nucleus at a distance scale of 0.1 fermi ($10^{-16}$ m), about a tenth of the width of a proton. In this situation, an individual quark, rather than the entire nucleon, absorbs the momentum of the collision. This was surprising, since the 0.1-fermi distance scale is larger than many current theoretical expectations for the onset of quark-counting-rule behavior.

*Editor's note: Results from this experiment were published in the Sept. 3, 2001 issue of Physical Review Letters by E. C. Schulte et al.*

# GRADUATE STUDENTS A LINCHPIN OF JLAB OPERATIONS

Creating a pipeline for electrons is not Jefferson Lab's only institutional goal. Equally important is funneling knowledgeable, highly-skilled individuals into both experimental and applied research programs in the United States and abroad. From JLab's birth, graduate students have been involved in all aspects of nuclear physics research, from equipment setup to data analysis. The Lab's extensive graduate-student program exists to foster and sustain such expertise.

At any given time, up to 200 graduate students are involved in the Lab's experiments, with seasonal fluctuations. Why is that? Jefferson Lab, as with all national labs, provides large "cutting edge" tools students would otherwise not have access to. This access promotes state-of-the-art science for our graduate students. Nearly all students have formal ties to the approximately 100 colleges and universities that conduct research at the Lab. More than 160 Ph.D. candidates are currently participating in experimental or theoretical research. (In all, the Laboratory's user community includes almost 1,600 researchers from 296 institutions, representing 38 countries and 31 states, including the District of Columbia.)

"JLab is not an educational institution per se. We confer no degrees," says Robert Welsh, chancellor professor of physics at William and Mary College and head of the JLab student affairs office. "But the Lab takes very seriously the idea that one of our primary goals is to produce very high quality, technically capable individuals even as we advance scientific knowledge."

Students are encouraged to have regular contact with the Lab's student affairs office. The office sponsors monthly luncheons, during which leading theoreticians and experimentalists report on the progress of their work. Also popular are summer seminars, which include specialized programming classes. Welsh is also in the process of getting courses at local institutions easily available and affordable for graduate students not living in Virginia, which may reduce the time to earn a Ph.D. in physics from five years to four.

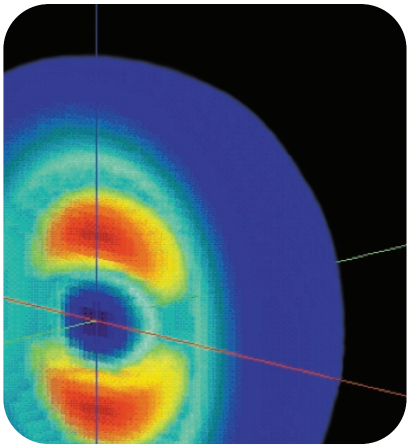
JLab's Graduate Student Association has a subsite on the Lab's Web pages, with links to organizational and local information. As a result of surveys and feedback from past and current graduate students, managers continue to address the concerns of the graduate student population and implement changes based on their suggestions.

Noting a chronic under-representation of women and minorities in physics, the Lab continues its active cooperation with historically black colleges and universities to promote science education and training. JLab currently has eight formal agreements to encourage minority participation in nuclear physics.

"My perception is that the Lab has an unusually high graduate-student satisfaction level," Welsh says. "I'd like to think it is because management here at JLab has worked hard to make sure things go smoothly. For whatever reason, there's an esprit here. And I think the local area [around the Lab] also has a certain attraction."

Attention to the details has made a difference, according to Welsh, who says the Lab routinely receives inquiries from post-grads eager to remain after their Ph.D. is complete.

*Right:* Bob Welsh (background) with graduate students who are an integral part of Jefferson Lab.



# USER GROUP BOARD OF DIRECTORS REPORT

February 12, 2001
(C. Glashausser)

*Editor's note: The users at Jefferson Lab help guide the activities of the users. The User Group Board of Directors is elected by the body of users at the Lab and enthusiastically serve the needs of their colleagues.*

The User Group Board of Directors meets three times per year: at the Annual Users Meeting in June, once in the late fall, and once in the early spring. The members from June 2000 - June 2001 were Gary Adams (RPI), Gail Dodge (ODU), Haiyan Gao (MIT), Charlie Glashausser, chair (Rutgers), Mark Jones, postdoc representative (JLab), Dave Mack (JLab), Rory Miskimen (U. Mass.), Alan Nathan, chair-elect (Illinois), and Alicia Uzzle, graduate student representative (Hampton). This is the first year that postdocs and graduate students have explicit representation on the Board. Each member of the Board has a specific area of responsibility, e.g., health and safety issues, running experiments, computing, and reports to the Board on issues in that area at each meeting.

The major activity of the Board over the past two years has been the organization of user activities in support of the 12 GeV upgrade. After conversations with management, members of the BOD helped arrange the general 12 GeV workshop in January, 2000, which led to a series of workshops on specific areas of interest during the spring and early summer. The June Users Meeting was almost entirely devoted to the presentation and selection of detailed proposals for submission to the Program Advisory Committee (PAC) in July. Along the same lines, BOD members arranged workshops on the physics and

# PROGRAM ADVISORY COMMITTEE

**Peter D. Barnes (Chair)**
**Jurgen Ahrens**
**Henk Blok**
**Peter Bosted**
**Frank Close**
**James Friar**
**Michael Garcon**
**Barbara Jacak**
**Stanley Kowalski**
**Gerald A. Miller**
**Alan Nathan**
**Shelley Page**
**Mauro Taiuti**

*Right:* Charlie Glashausser, User Group Board of Directors chair, and Christoph Leemann, Jefferson Lab director.

equipment for the 12 GeV upgrade to accompany the American Physical Society's Division of Nuclear Physics (DNP) meeting in Williamsburg, Va., in October, and participated in the DNP Hadronic Physics Town Meeting in December.

Among the other activities of special note was the awarding of the first SURA thesis prize to Ioana Niculescu of Hampton University and Bart Terburg of the University of Illinois. The next prize went to Maud Baylac of the Universite Claude Bernard and Commissoriat a L'Energie Atomique. The prize is sponsored by SURA, and consists of $1000 and a plaque.

A survey of user satisfaction covering quality of life issues at JLab was conducted to obtain a more quantitative estimate than the usual anecdotal information. The survey did support the Board's impression that users were generally happy with the working and living environment at the Lab, though some dissatisfaction was noted in the areas of radiation training, offices (particularly in the trailers), and computers for short term visitors. Remedial actions have been undertaken by management in all of these areas.

According to the survey, close to 90 percent of respondents said they enjoyed working at the Lab, while 94 percent found the scientific staff "knowledgeable and helpful." Staff was generally credited with making life far easier in most administrative matters.

## STATUS OF EXPERIMENTS

| # of Approved Experiments<br>Topic | Hall A | Hall B | Hall C | Total |
|---|---|---|---|---|
| Nucleon and Meson Form Factors and Sum Rules | 7 | 4 | 8 | 19 |
| Few Body Physics | 13 | 5 | 5 | 23 |
| Properties of Nuclei | 6 | 10 | 8 | 24 |
| N* and Meson Properties | 6 | 26 | 7 | 39 |
| Strange Quarks | 4 | 11 | 2 | 17 |
| Total # of Approved Experiments | 36 | 56 | 30 | 122 |
| Conditionally Approved (#) | 4 | 6 | 2 | 12 |

| Hall | # of Expts. complete | # of expts. partially complete | Equiv. total for partially complete expts. | Equiv. Total for all expts. complete | Total Days Run | # of Expts. in Queue | Days to be run | Conditionally Approved Expts. |
|---|---|---|---|---|---|---|---|---|
| A | 18.0 | 4.0 | 1.96 | 19.96 | 394.90 | 13.14 | 288.00 | 4 |
| B | 9.0 | 38.00 | 20.82 | 29.82 | 313.90 | 26.18 | 300.10 | 6 |
| C | 15.0 | 2.00 | 1.00 | 16.00 | 338.50 | 13.62 | 231.40 | 2 |
| Total | 42.0 | 44.00 | 23.77 | 65.77 | 1047.30 | 52.95 | 819.50 | 12 |

| Backlog Estimates | Hall A | Hall B | Hall C | Average |
|---|---|---|---|---|
| To be scheduled | 3.47 | 2.82 | 3.61 | 3.30 |
| Already scheduled | 0.76 | 0.74 | 0.55 | 0.68 |
| Total | 4.23 | 3.57 | 4.16 | 3.99 |

# JLAB BUILDS NEW GENERATION OF SUPERCOMPUTERS FOR SCIENTIFIC RESEARCH

*Editor's note: As part of the Lab's nuclear physics mission, Jefferson Lab is developing cost effective computer clusters of commodity computers for nuclear theory, with a particular emphasis on state-of-the-art theoretical computer calculations to compare to experimental results, vital to the Jefferson Lab nuclear physics program. This leadership role in advanced computing is crucial to the Lab's continued prominence in the nuclear physics community.*

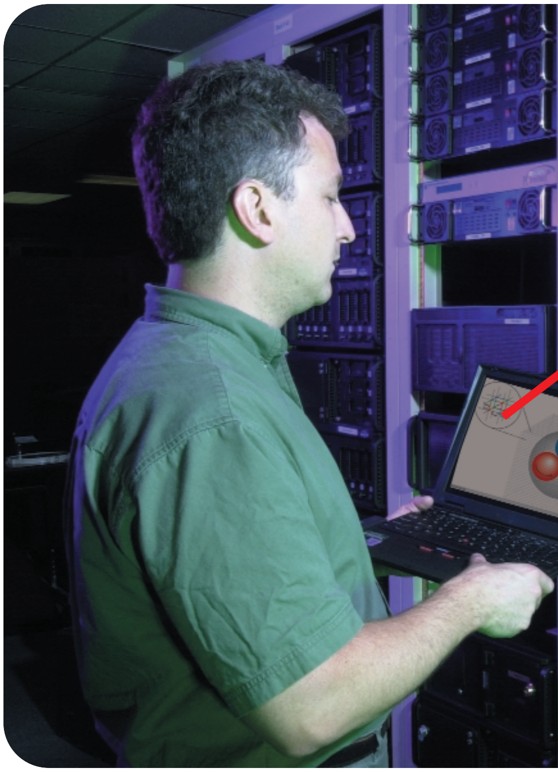
When massive amounts of computation are required, researchers need more than a scratchpad and a couple of sharpened pencils. In order to better calculate and mathematically model the complex interactions deep within the atomic and subatomic realms, Jefferson Laboratory has become involved in the Scientific Discovery Through Advanced Computing project, or SciDAC, which is funded by the Department of Energy. SciDAC aims to tackle some of the most difficult projects facing scientific research.

In general, the increased computational brawn should lead to significant advances in the modeling of the complex behaviors of atoms, molecules, fluids, materials, and of biological, climate and physics-related systems, such as nuclear fusion. More specifically, Jefferson Lab's participation in the project should enable its accelerator to run more efficiently, provide users more power for data analysis and interpretation, and aid theorists in developing a more complete understanding of atomic nuclei.

Included among the examples of calculation-intensive issues that JLab expects to address are much faster analysis of the huge volumes of data being produced by experimenters in the Lab's three experimental halls; the intensity and focus of the accelerator's electron beam; studies of the complex interplay of particles and forces within an atomic nucleus; and verification of the equations describing the quark theory of matter that underlies all of the Laboratory's nuclear physics experiments.

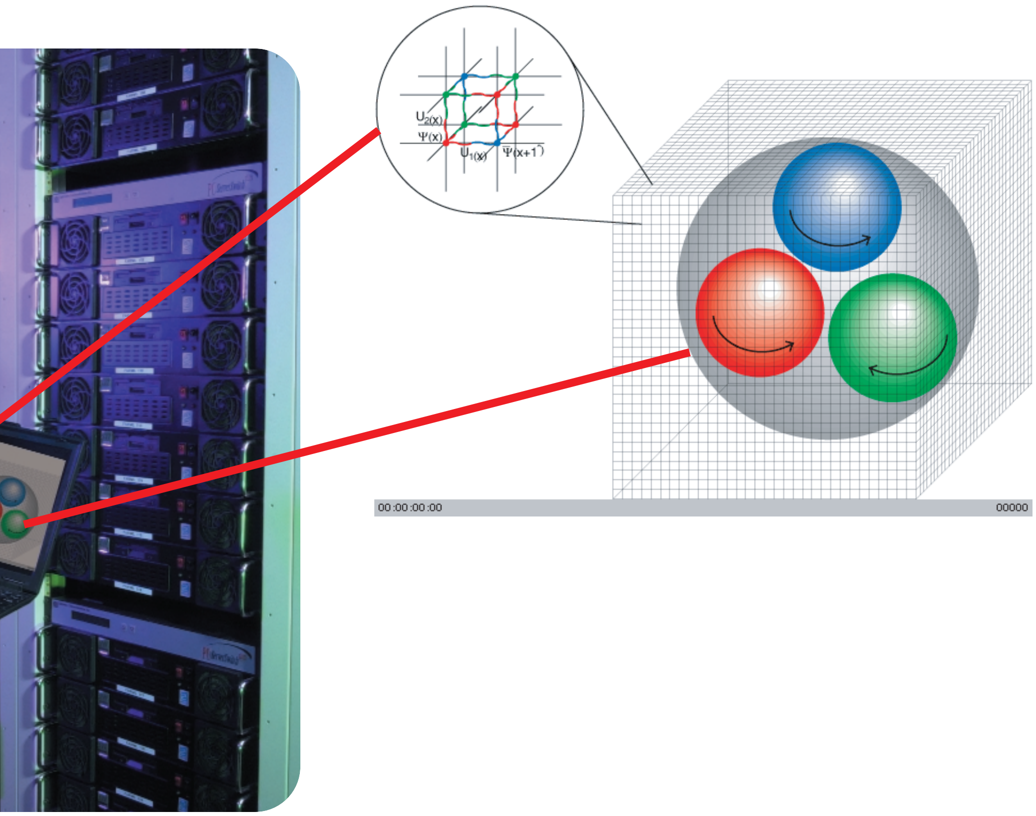
SciDAC's approach at the Lab is to buy relatively small processors and yoke them together in parallel, in essence creating affordable supercomputers at a fraction of the cost that otherwise would be incurred. Most personal computers are based on serial processors and algorithms that carry out instructions in a set sequence, one after another. Parallel computation derives its speed from a software strategy that subdivides calculations into discrete subtasks and then executes them simultaneously.

As more processors are added, the number of mathematical operations per second — expressed



in the acronym "flops," for floating-point operations per second — will likewise soar. The first JLab home-grown supercomputer, with 128 microprocessors working in tandem, will calculate at the 100-gigaflop range; that is, executing 100 billion floating-point operations per second. A 200-gigaflop scale-up, to 256 microprocessors, is expected by the end of 2002. By 2005, giga should give way to tera, or trillions of operations per second.

The incremental approach will allow for a relatively inexpensive purchase of calculating power, which, because of a modular structure, will be able to easily accommodate expected future performance gains from newer generations of microprocessors. In essence, says Chip Watson, head of high-performance computing for Jefferson Lab, the Lab will be




*Left:* A four-dimensional lattice representing three-dimensional space and one dimension of time. Shown are the three “colors” (charges) of quarks predicted by the Quantum Chromodynamics (QCD) theory. The smaller inset shows the sites of the lattice which constitute a proton. The gluons (the mediators of the forces in QCD) are on the links.

building a supercomputer successor every 36 months.

"We’ll be buying a new machine every three years," he points out. "Every three years the machine will be four times faster. Ten years from now we’ll be looking at machines in the 100 teraflops range — roughly 16 times faster."

Cluster supercomputers, such as those funded by SciDAC, should stimulate progress in advanced materials development, like the next generation in high-temperature alloys, as well as improved magnetic photovoltaics for solar cells and atom-size components that will comprise future computers. By permitting many more and faster calculations, cluster super computers should allow scientists to save enormous amounts of time when formulating theorems prior to experiment design.

For physics researchers, more powerful computation should allow for more complete examination of a mathematical approach to solving quantum chromodynamics theory, or QCD, known as lattice QCD. This theory attempts to explain the behavior and interactions among quarks, believed by many physicists to be fundamental building blocks of matter. Mathematical aspects of this theory are still poorly understood and appear amenable only to more advanced calculation.

"There’s never enough computational capacity in the world," Watson says. "That’s especially true for lattice QCD. It’s a very difficult problem."

Enhanced computation prowess will also be required as the Lab moves ahead with a planned electron-beam energy doubling, from 6 billion electron volts, or 6 GeV, to 12 GeV starting in 2006. Addition of a fourth experimental hall during the upgrade is expected to add one petabyte, or 100 million gigabytes, yearly of data to be taken and analyzed. The Lab will also be making available to researchers "portals," which will allow researchers to access the supercomputers at JLab and other federal labs across distributed computer networks.

"It’s hard to imagine what’s beyond the 100-teraflop range," says Watson. "We just don’t know what will happen when we begin to compute at that scale. We don’t know what interesting physics will be revealed."

# ACCELERATORS

## CEBAF PERFORMANCE

Jefferson Lab's CEBAF accelerator has become an ever more reliable tool for researchers since it began operating for science in the mid-1990s. "CEBAF now runs reliably over extended periods," says Operations Director Andrew Hutton. "In fiscal year 2000, we delivered 5614 hours of beam for our experimental users. In the first six months of fiscal year 2001, the number of experimental halls conducting experiments averaged 2.94 out of a possible 3.0 — and the goal was only 2.0. During those six months we supported a total of six different experiments."

The accelerator was originally designed for 4 GeV, but has continued to improve in energy. Initial cavity performance provided a reliable energy in excess of 5 GeV, limited by electron field emission. To reduce the field emission and boost the operational energy, a program was begun to process the accelerator's cavities in place, in the tunnel. This in situ helium processing led to a demonstration of the capability for a full 6 GeV during 2000. The accelerator now operates regularly for physics at 5.7 GeV.

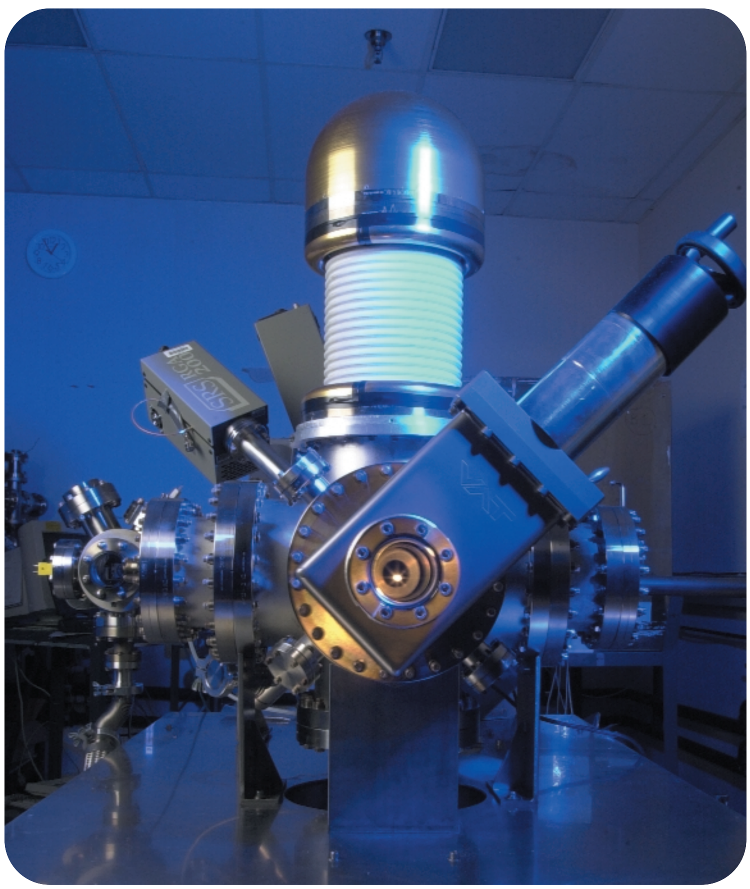
### POLARIZED ELECTRON SOURCE

The delivery of highly polarized electron beams at high average current sets CEBAF apart from other accelerators worldwide. In a polarized beam, the spin of the electrons is oriented in one well-defined direction. Polarization helps reveal key aspects of nuclear structure — as in a recent Hall A experiment, for example.

The accelerator has demonstrated 80% polarized beam at an unprecedented average current of more than 200 microamperes. This capability resulted from years of effort by Charles K. Sinclair and the Jefferson Lab Injector Group. During a ceremony formally recognizing their work, Jefferson Lab Director Christoph Leemann emphasized the difficulty of their achievement. "A polarized electron beam is an induced state of matter, with everything working against you," he said. "It took a strong multidisciplinary team to bring us to the forefront."

The accelerator has one polarized source in operation, and a second, identical source ready and available. Having two sources allows operation with one while the other is undergoing work, minimizing this system's potential for interrupting the experimental program.

In either source, circularly polarized laser light strikes a photocathode — a wafer of gallium arsenide — and causes it to emit electrons. The key development challenge has been to extend the operating lifetimes of



*Above:* New injector gun (load-lock) under development that could allow preparation of photo cathodes in situ.

these photocathodes. Initially they lasted only a few days. But gradually the Injector Group came to understand the problems, developed measures to correct them, and extended the time to periods of months.

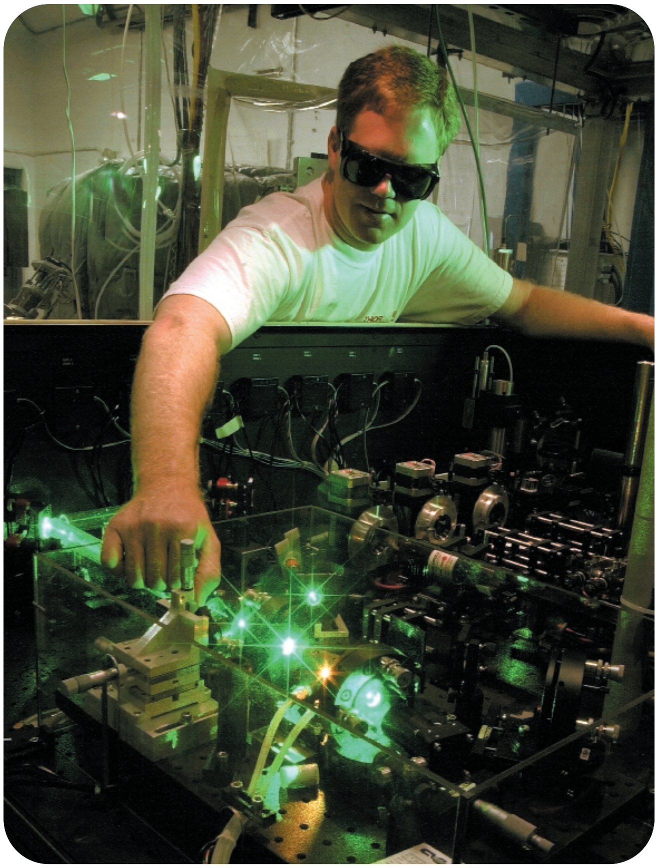
The Injector Group has found it useful to describe photocathode lifetime in units of electric charge yielded per unit of area illuminated by the laser light. The operational lifetimes of CEBAF's photocathodes now routinely exceed 100,000 Coulombs per square centimeter — performance unparalleled anywhere.

In fact, the photocathodes have become so reliable that the Injector Group has simply removed the unpolarized injector. In no other accelerator do the polarized guns deliver all beams, both polarized and unpolarized. This high level of reliability marks a notable advance in the state of the art.

The Injector Group recently overcame another chronic practical problem as well with experiments involving extremely fine measurements made in conjunction with changes in the beam polarization. These measurements take advantage of parity violation, the phenomenon that the nuclear weak force reveals and that provides in nature a fundamental distinction between left and right. The problem was that unwanted and relatively large position and charge differences in the beam accompany the polarization changes.

Because these differences are nearly one hundred times harder to control than in beams originating from low-polarization cathodes, other laboratories have been reluctant to use high-polarization cathodes for parity-violation-based measurements. Jefferson Lab was the first to demonstrate successful control at the level required for this exquisitely fine work. Because future experiments will require even tighter control, the Injector Group will continue working to minimize or eliminate the unwanted changes in the beam's characteristics.

Polarization manipulation and control, and the ability to deliver highly polarized beams at high current to more than one hall simultaneously, have become essential capabilities at Jefferson Lab. The experimental program requires polarization in more than one hall the majority of the time. Simultaneous delivery of highly polarized and nominally unpolarized beam has become routine.



*Above:* John Hansknecht adjusts the Ti sapphire laser in the injector region of accelerator. This system is used to produce high-polarized, high-current electron beam.

"Our capabilities will make unprecedented studies of parity violation possible, and these studies can be used for new purposes," says Sinclair. "For example, take one of the new Hall A experiments. In the past, it's been exceptionally difficult to verify theoretical predictions that the neutron radius in lead is slightly larger than the proton radius. We knew that parity violation could let us measure that tiny difference, because polarized electrons interact differently with protons and neutrons through the weak force. But we needed the right polarized beam — and now we have it."

# 12 GEV CEBAF ENERGY UPGRADE

*Editor's note: Plans are being made to expand the nuclear physics program to continue reaching into the frontiers of hadronic physics and to investigate the gluons that hold quarks together. Below is the current status of that push.*

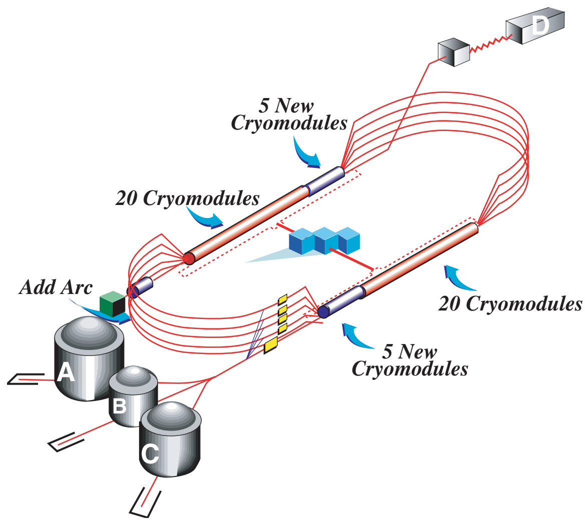
Jefferson Lab's upgrade to 12 billion electron volts, or 12 GeV, has been formally recommended by the Nuclear Science Advisory Committee (NSAC), a group of distinguished physicists that counsel the Department of Energy and the National Science Foundation on research priorities. The Committee describes the upgrade as "critical" to American nuclear physics studies and notes that a beam-energy doubling will provide new insights into the structure of nuclear particles. Higher beam energies will provide users with a tool to study the transition between the atomic and sub-atomic realms; provide much better understanding of quarks, those subatomic particles believed to be the basic building blocks of all matter; and reveal more of the form and function of gluons, those force-carrying particles that constrain and influence quark movement. "The NSAC recommendation represents the validation by the larger community of a lot of hard work by the JLab users and staff to define the directions of the next decade of research in hadronic physics," notes Larry Cardman, JLab associate director of physics. "We're excited by the new avenues of research it will open."

JLab managers note that technological progress and built-in economies of scale will make the upgrade technically and economically feasible. The Lab's current beam energy of 6 GeV can be doubled for roughly 15 percent of what it would otherwise cost, assuming that a comparable facility had to be built from the ground up.

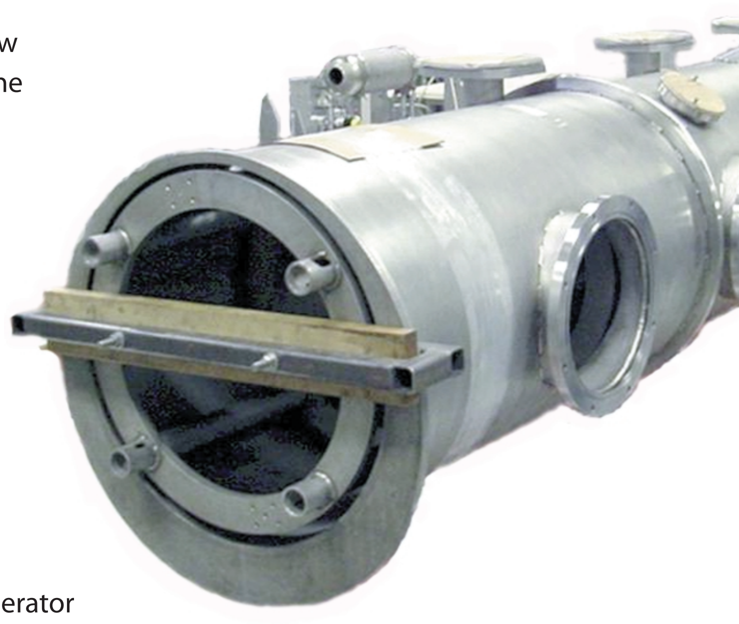
"The amount of new physics that can be done for the money spent is a real benefit," says Cardman. "This laboratory is playing a key role at the forefront of nuclear physics. Everyone recognizes that an upgrade makes sense."

Researchers will enlist the unique properties of the Lab's energy-upgraded accelerator to include the spectroscopy of quark-antiquark systems to study gluon excitation. Scientists will thus have an even more powerful tool for investigating the transition from the regime in which conventional descriptions of nuclear matter applies, to a less-understood area where underlying quark "degrees of freedom" become evident.

Such studies should provide key insights into how matter is constructed from quarks and gluons, complementing the work already underway in Lab halls at lower energies. Advocates believe that investigations at 12 GeV will keep the American nuclear physics program at the cutting edge of physics research worldwide. A beam-energy increase would




*Above:* Schematic of proposed 12 GeV upgrade. New accelerator components, additional magnets and a new experimental Hall D are all part of the proposal.



*Above:* Prototype of newly reconfigured cryomodule shell.

substantially enlarge research opportunities for the entire nuclear physics community.

"At 12 GeV, we can investigate parts of the atom we couldn't at 6 GeV," says JLab Director Christoph Leemann. "For instance, we will examine the decays of a class of particles known as hybrid mesons, created as a result of reactions with high-energy photons. What one expects to find are certain states that could prove or disprove our current theories. The 12 GeV upgrade is what we believe we'll need for vital and forefront physics into the third decade of this century. It buys us long life, scientifically speaking. We are unique today at 6 GeV. At 12 GeV we'll maintain that uniqueness."

Funding needed for the upgrade is estimated at $150 million, which is being requested from DOE. The task confronting upgrade planners was to devise a higher-energy configuration that will be both economical and efficient. To that end, planners will fully exploit the accelerator tunnel's total capacity for 50 eight-cavity cryomodules in both accelerator linacs, plus several more in the injector region. Currently, 41 and 1/4 cryomodules are used to deliver beams up to 6 GeV.

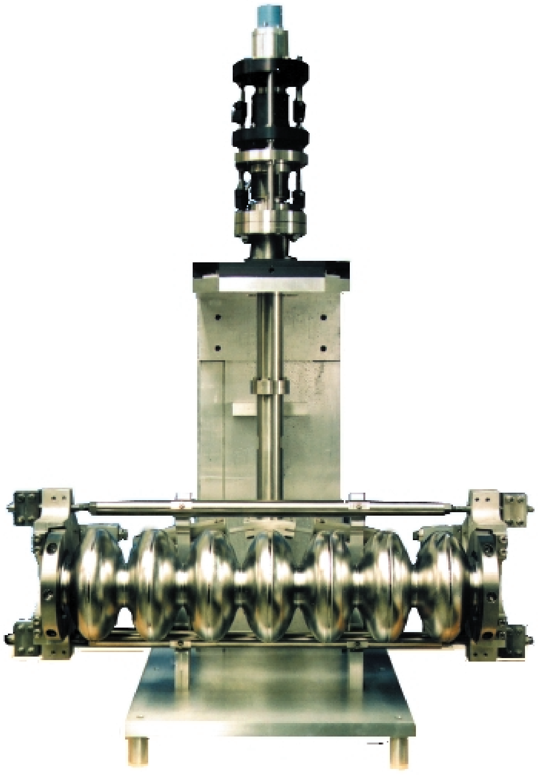
Future cryomodules will be assembled in groups of eight 7-cell cavities, rather than the previous configuration, which involved sequential assembly of four 5-cell cavity pairs. The new arrangement will substantially improve accelerator performance and increase operational efficiency.

The cavities are the innermost components of the cryomodules which also include a cooling tank of liquid helium and a Thermos-bottle-like structure known as a cryostat. The cryostat provides insulation allowing the cells to remain cooled by the helium at two Kelvin, nearly absolute zero.

In order to reach the 12 GeV mark, engineers must develop, install and commission 10 of the redesigned cryomodules. Each upgraded unit will have a capacity of over 100 megavolts, more than triple the present levels. The first prototype group of reconfigured cryomodules is scheduled for installation and testing in 2003, with the remainder slated for installation as monies become available.

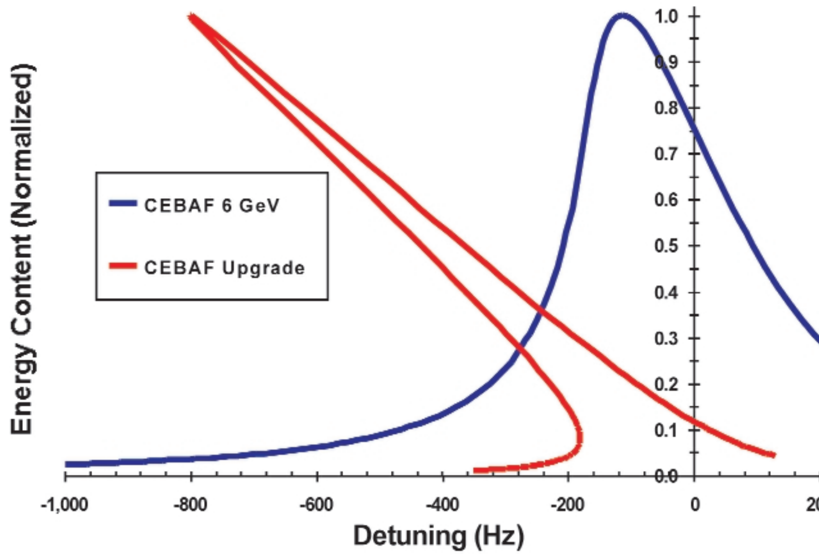
The cost of each cryomodule won't increase from present levels, but will include more voltage per module, which will translate into higher electron-beam energies. The 12 GeV upgrade could begin as early as 2005, or as late as 2007, with a one-year accelerator shutdown followed by a recommissioning before physics begins again at the higher energy level.

"I'm optimistic," Leemann asserts. "This [upgrade] is truly fundamental — essential science. It has to be done to close the gap in our knowledge about how nucleons and nuclei are built up from quarks. There's a very strong scientific rationale for this project. Given the fact that we can practically apply what we've already learned about superconducting accelerator technology, it will also be very cost effective."



*Above:* The new seven cell cavity design, shown with its external tuning assembly, will help the Lab achieve higher electron-beam energies.

# CENTERS OF EXCELLENCE




### Institute for Superconducting Radiofrequency Science and Technology

Jefferson Lab's core strength and competency in R&D and large scale application of RF superconductivity in its facilities are recognized internationally. Not only has the application of SRF resulted in an accelerator where performance has greatly exceeded design and is continually improving, it has also enabled another application at the Laboratory, the Free-Electron Laser. SRF is also being applied to, or considered for, an increasing number of facilities nationally and worldwide. Because of its outstanding combination of expertise, experience, and facilities, Jefferson Lab is in a unique position to contribute to a host of future accelerator projects by remaining at the cutting edge of SRF science and technology. While some of the projects being contemplated require only modest improvements of SRF technology, others will require radical new approaches and breakthroughs in material science as well as accelerator structures design and control.

SRF is not a stand-alone discipline but a multi-disciplinary scientific activity that includes solid state physics, surface science, low temperature physics, electromagnetism, radio frequency and microwave, feedback and control systems, beam-RF interactions, and vacuum science, as well as mechanical engineering and cryogenics. The greatest advances in the application of SRF to accelerators will require a close collaboration and integration between these various areas of expertise.

In order to further maintain and enhance its primary core competency in the area of superconducting radiofrequency cavity and linear accelerator technology and to give SRF the level of visibility commensurate with its importance to the Lab and the accelerator community, Jefferson Lab has created a centralized professional research, development and production center, the Institute for Superconducting Radiofrequency Science and Technology. The Institute incorporates the associated disciplines of radiofrequency power and its control, research and development of novel cavities, surface science studies, cryogenics and cryomodule production capability, and electromagnetic and particle beam driven test facilities. The Institute includes Jefferson Lab's SRF Test Lab and the FEL beam facilities as its primary test facilities and is chartered with staying abreast of the production of state-of-the-art SRF cryomodules for current and possible future accelerator projects such as the SNS, RIA, the 12 GeV CEBAF energy upgrade, TESLA, etc.

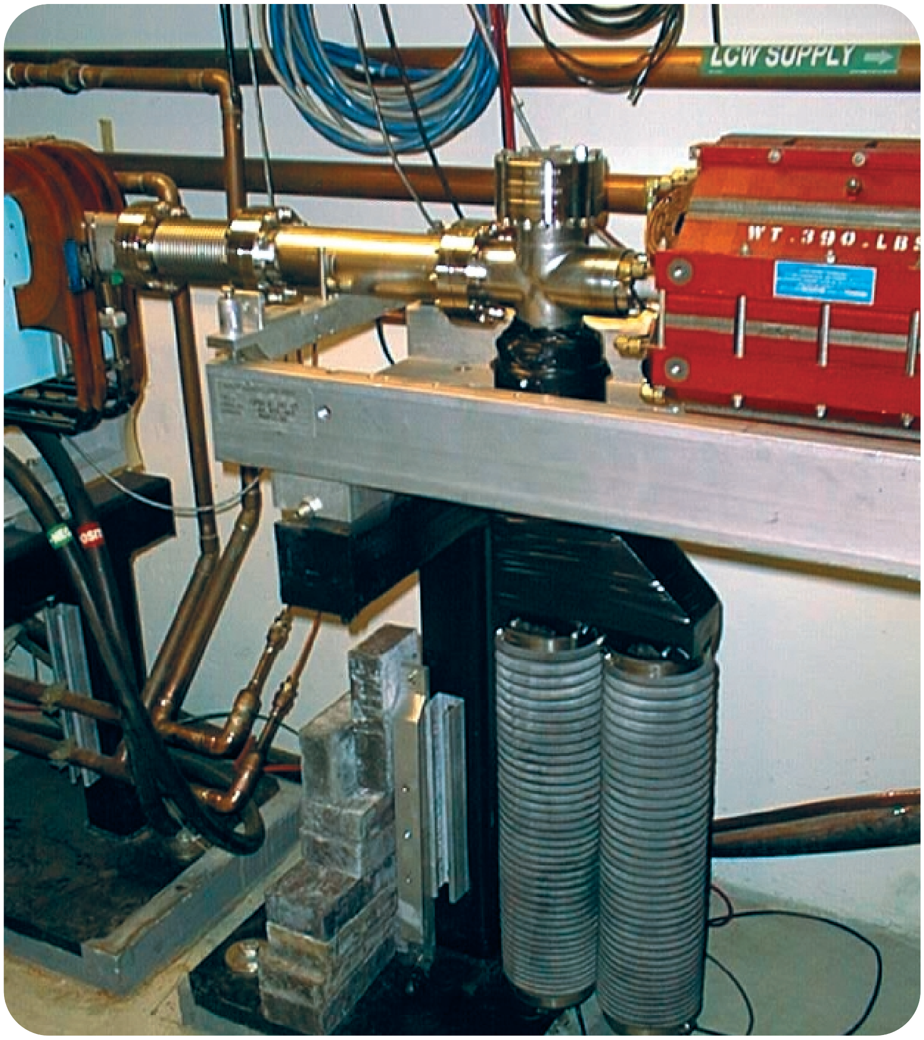
Simultaneously with production capabilities, the institute is chartered with taking bold steps in its R&D effort, pushing the SRF potential to its fundamental limits and pointing to further technological breakthroughs. Concurrent with the programmatic goals of production and R&D, the Institute is establishing its own information management architecture to ensure archival of various procedures and SRF related data, create an educational training and mentorship program in partnership with senior Lab management and universities worldwide, participate in technology transfer and other SRF applications and maintain its globally competitive status by establishing collaborations and partnerships with institutes worldwide. It will serve as a training ground for the next generation of SRF physicists through support of students, postdoctoral fellows, and visiting scientists.

**Center for Advanced Studies of Accelerators**

The accelerator physics community at Jefferson Lab is a precious resource being shared and called upon by various departments in the Laboratory — the CEBAF and FEL operations, SRF physics, beam measurements, and control.  At the same time, this group is responsible for aggressively promoting new initiatives at the Laboratory based upon its core competencies of beam and radiation physics, SRF science and technology and various particle source technologies.

These resources have contributed to the success of the CEBAF accelerator and the FEL facilities and have initiated a great many new ideas in the field that are being rapidly recognized by the international community. Examples of these new initiatives include the Lab's proposed 12 GeV and 24 GeV upgrade projects, a possible high-luminosity electron-ion collider facility for nuclear physics, the principle and technical demonstration of Energy Recovered Linacs (ERLs) and their application as electron coolers in possible future electron-heavy ion collider facilities such as the e-RHIC that is being considered at Brookhaven National Lab, future light sources, etc.

In order to further enhance the primary competency of Jefferson Lab in accelerator science and technology and to bring it to the level of visibility commensurate with its importance to the Lab and the community at large, Jefferson Lab has created an integrated center of excellence in accelerator science, the Center for Advanced Studies of Accelerators. The center incorporates all related disciplines in particle and photon beams — dynamics, optics, sources, instabilities and their control, various incoherent and coherent radiation phenomena and numerical simulation of particle and light beams. In partnership with the SRF Institute and other departments at the Lab, the center has the charter of not only supporting on-going activities at the Lab, but to look after and promote boldly future options in sub-atomic physics.




*Above:* First light-based beam charge asymmetry detector useful for controlling polarized low-current beam for Hall B.

# LAB'S SNS INVOLVEMENT ACCELERATES

Jefferson Lab is a principal contributor to a major, new, basic-energy-sciences research installation scheduled for completion by 2006. The Lab is part of a team of federal laboratories — including Argonne, Brookhaven, Lawrence Berkeley, Los Alamos and Oak Ridge — collaborating in the design, engineering and construction of the $1 billion-plus Spallation Neutron Source (SNS) in Oak Ridge, Tenn. The SNS will provide the most intense pulsed-neutron beams in the world for scientific research and industrial development.

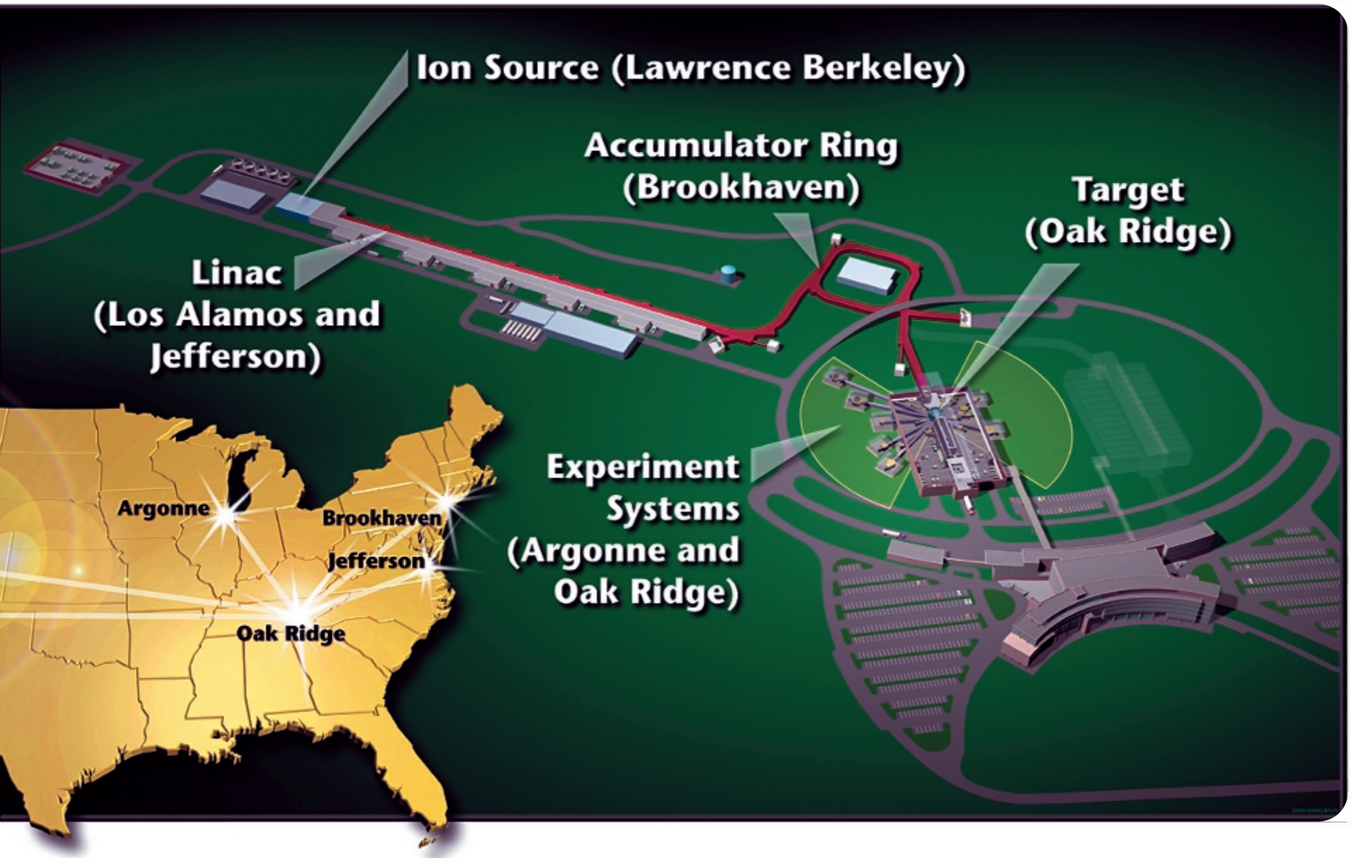
JLab's responsibility is to engineer and assemble SNS cryomodules in Newport News and to oversee the installation and initial operation of cryomodules and helium refrigeration equipment at Oak Ridge. As at JLab, superconducting radio-frequency (SRF) technology and advanced cryomodule design will be incorporated within the SNS accelerator complex to enable low-cost, high-efficiency operation. The first of several prototype six-cell cavities has achieved acceptable performance in vertical test. Components for the first prototype cryomodule arrived at JLab in late summer 2001. "Jefferson Lab is the only federal research facility that specializes in large-scale application of SRF technology," says Swapan Chattopadhyay, associate director of the JLab Accelerator Division. "The project will make use of and benefit from our core technology."

Above: Sam Morgan polishes one-half of a SNS cavity cell made from Niobium.

The aggregate effort of JLab employees, permanent and contract, full- and part-time, reassigned to SNS activities from other JLab-specific duties or brought on especially for SNS, is equivalent to 50 full-time employees. Additional staff, consisting of SNS employees who will come to JLab to learn about cryomodule assembly and operation as part of the technology transfer component of the collaboration, will be added as the Lab's involvement peaks.


Even though Lab managers had been involved in informal discussions early on, JLab's formal involvement in the SNS project dates back only to the summer of 1999, when discussions outlined the Lab's envisioned participation. Research and development is occurring at an accelerated pace, at least compared to the Lab's own genesis: roughly 10 years passed from groundbreaking at JLab's Newport News, Va. site to routine electron-beam availability to experimentalists.

When the SNS facility is complete, researchers will be able to obtain detailed snapshots of material structure and stop-action images of molecules in motion. Similar to a flashing strobe light




providing high-speed illumination of an object, the SNS will produce pulses of neutrons every 17 milliseconds, with more than 10 times more neutrons than are produced at the most powerful pulsed-neutron sources currently available. Neutrons from the SNS beam will scatter from a target material in a way that reveals that material's structure and properties.

SNS funding is being provided by the U.S. Department of Energy's Office of Science, Basic Energy Sciences Division, with $8 million in additional monies coming from the state of Tennessee. Final siting at Oak Ridge was approved in June 1999, and groundbreaking occurred six months later, on December 15.

## Rare Isotope Accelerator (RIA)

The physics community is exploring the possibility of building an accelerator-based facility that would study the "chemistry" of nuclear physics. The Rare Isotope Accelerator (RIA) would provide to researchers high-intensity, high-resolution accelerated beams of rare radioactive ions, many of which are thought to normally exist only briefly as a byproduct of stellar explosions.

While the final decision on the construction of the RIA facility has yet to be determined, some of the technology that would be used to build RIA already exists. The SRF technology developed and maintained at Jefferson Lab allows the Lab to make state-of-the-art contributions to this new project.

# FREE-ELECTRON LASER

Successful as the Jefferson Lab Infrared "IR Demo" Free-Electron Laser (FEL) has been since it began operating in 1999, it was always planned as the initial, dramatic demonstration of a technology that would be developed much further. The ultimate goal was always to move well beyond the constraints and limitations that stop conventional lasers from providing the full benefits of coherent, monochromatic laser light.

That's why a Jefferson Lab FEL upgrade is already under way. "This upgrade serves the interests of stakeholders from defense, from basic science, from universities, and from industry," says FEL Program Manager Fred Dylla. "It was only two years ago that we smashed the record for high average power in a tunable laser — by two orders of magnitude. Now we're excited about moving up the next order of magnitude."

In the long term, the FEL program seeks to lower the cost of laser light, to increase lasers' capacity for supporting research, industrial work, and defense functions, to throw open access to a huge range of useful individual colors of infrared (IR) and ultraviolet (UV) laser light, and to give laser users the tremendous advantages of applying the light in extraordinarily brief pulses.

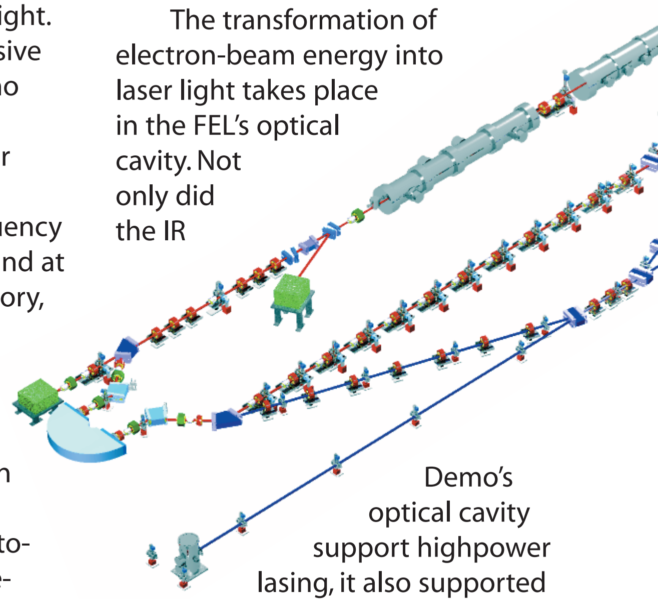
The first step in that long-term program is now complete. The IR Demo began by producing a record-smashing 1.7 kilowatts in 1999. For two years, while its builders have continued to improve it, the IR Demo has served a growing clientele of user-stake-holders. Now a number of lessons learned from this IR Demo effort are guiding the upgrade effort. For instance, the IR Demo machine demonstrated the high current energy recovery, which is crucial because conventional free-electron lasers typically transform only about 1% of the FEL "driver" electron beam's energy into light. Rather than waste the expensive 99% that remains, the IR Demo recycled the electron beam through the driver accelerator and recaptured most of the unspent energy as radiofrequency power. At Cornell University and at Brookhaven National Laboratory, scientists are now designing new light sources using this capability.

In the driver accelerator's injector — where the electron beam originates — the elec-tron gun's direct-current photo-cathode met rigorous require-ments for beam quality, for brightness, and for operational longevity. The photocathode is the actual source of the "free" electrons. To replace a spent photocathode takes time and disrupts operations. Increasing the longevity of photocathodes has been an important contribution to accelerator and light-source technology in general, as discussed in the CEBAF accelerator section of this highlights report. The elec-tron-beam "halo" generated in the injector was also well controlled, as were a variety of effects in the driver accelerator itself.

The transformation of electron-beam energy into laser light takes place in the FEL's optical cavity. Not only did the IR Demo's optical cavity support highpower lasing, it also supported generation of laser light at the second, third, and fifth harmonics, which are simple multiples of the fundamental operating frequency. That extra capability increases the laser's versatility.

Overall, the IR Demo's performance confirmed the

*Above:* FEL User Facility.



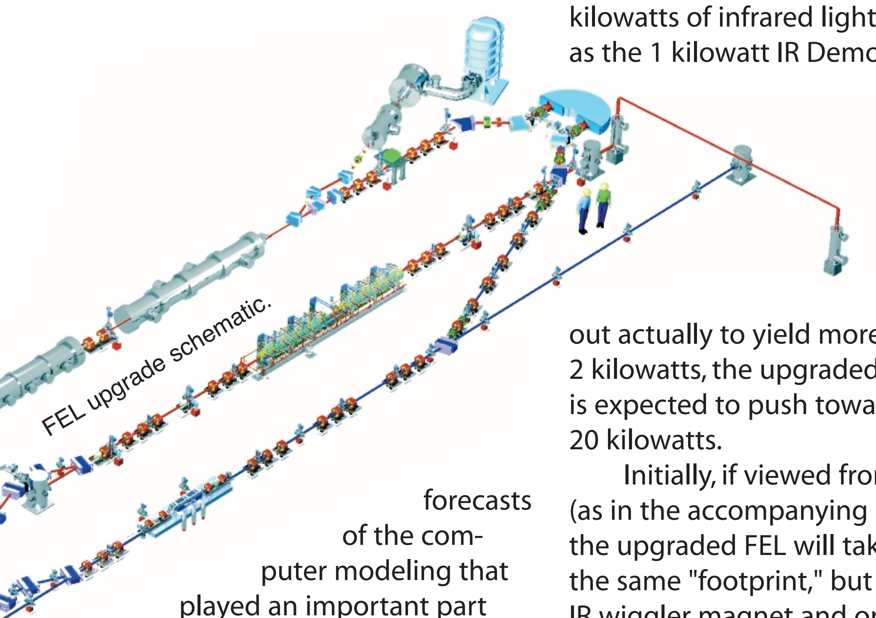
## FEL Program Advisory Committee (PAC) Members

**Trevor Sears**
*(Brookhaven National Lab)*

**Philippe Guyot-Sionnest**
*(University of Chicago)*

**Richard Haglund**
*(Vanderbilt)*

**John Sutherland**
*(East Carolina University)*



FEL upgrade schematic.

forecasts of the computer modeling that played an important part in designing and building the FEL. In turn, that's a confidence-builder for the upgrade task, because the benchmarking of computer models is a crucial part of the scaling-up process for any first-of-a-kind technological system. Hardware for the scaling-up now under way includes a new injector, which will double the electron-beam current, bringing it to 10 milliamperes — not much compared to household electricity, but substantial in the realm of electron beams. The IR Demo's driver has one cryomodule containing eight superconducting accelerating cavities. A second cryomodule will be added soon in the upgrade process. Later, a third cryomodule will be added as well. It will be of the higher-performing variety to be used in the 12 GeV upgrade of CEBAF. And it will represent yet again the synergy of the FEL with CEBAF, in that both programs contributed to, and will now profit from, the research and development that produced it. The driver in the upgraded FEL will provide a beam of free electrons to the laser not at 48 MeV (million electron volts), as in the IR Demo, but at 160 MeV. That will mean, initially, 10 kilowatts of infrared light. But just as the 1 kilowatt IR Demo turned out actually to yield more than 2 kilowatts, the upgraded FEL is expected to push toward 20 kilowatts.

Initially, if viewed from above, (as in the accompanying schematic) the upgraded FEL will take nearly the same "footprint," but the new IR wiggler magnet and optical cavity will be in the return side instead of in the side containing the driver accelerator. Later the footprint will get wider, when an alternate return side will be added. That one will contain a UV wiggler and optical cavity. Thanks to active control of the mirror radius of curvature in the optical cavity, plus high-quality coatings, powers up to 25 kilowatts will be manageable in the upgrade's IR optical cavity, with powers up to 1 kilowatt on the UV side.

Applications opportunities will continue to expand for users of the upgraded FEL. With its defense-agency funding, the upgraded system will obviously provide the new data and experience needed by developers of directed-energy systems. The Navy — which is providing $13.4 million of support for the upgrade — is interested in the conversion of electrical power into light without using up any consumable chemicals, and in the ability to color-tune to adjust to changing atmospheric conditions.

**Free-electron lasers (FELs) are capable of operation over the entire electro-magnetic spectrum and are rapidly filling spectral voids left by conventional sources. ... At present, there are two principal areas for future FEL development: higher average power and shorter wavelengths.**

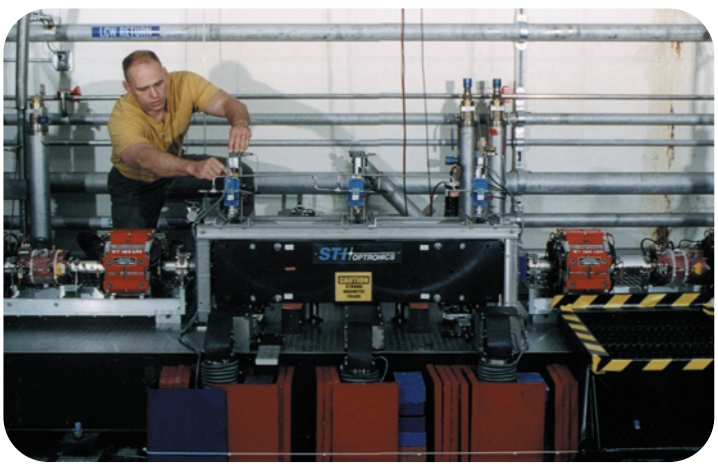
***Science*, *8* June 2001**

The upgraded FEL will also support both basic science and industrial research and development.

A June 2001 article in *Science* noted that the IR Demo's unprecedented performance "has opened the door for high-average-power applications in materials processing," and that "continued development of high-power FEL technology in the ultraviolet should produce considerable interest from industry."

Some users will use the light for basic electronic materials development and nanoelectronics studies, such as novel component design and fabrication approaches based on precise removal and deposition of materials. Others will conduct basic biological studies of the energy flows in proteins, or of the effect of UV light on human tissue. Still others will investigate


*Right:* The FEL control room with overhead monitors displaying each lab as experiments take place.



*Left:* The FEL wiggler has a series of magnets that "wiggle" an electron beam which produces the photons needed to create the laser.

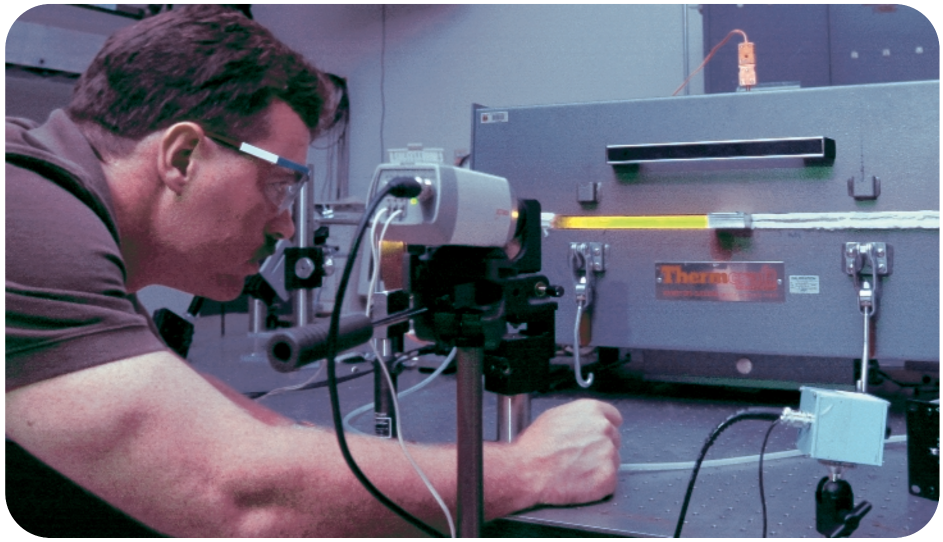
*Below:* The FEL beam (bright spot) is used experimentally to nitride the surfaces of metals.

the fast melting of surfaces to attain hardness, corrosion resistance, or antimicrobial effects, or will investigate ultraprecise drilling for channeling liquids and sprays in printer heads and in the fuel-handling components in engines.

To get this upgrade effort started, SURA initially provided over a half-million dollars. The Navy added \$9 million in June 2000, and another \$4.4 million the following February. With component construction under way, decommissioning of the IR Demo will start in December 2001, followed immediately by IR upgrade installation. First operation of the IR upgrade is planned for the fall of 2002. In September 2001 the Air Force provided \$3 million for the UV components that are to be installed.

The new FEL is being planned and executed with full mindfulness of the long-term goals of the Jefferson Lab FEL program. It represents a giant step in lowering the cost of light, one of the program's fundamental goals. Light at 1 kW from the IR Demo costs about a dollar per kilojoule. In the upgraded FEL, with its 10 kilowatts of IR light, that will fall by a factor of 5, to 20 cents. And this is all of course targeted toward yet another factor-of-5 cost-of-light decrease, sometime in the future, when still another upgrade will yield 4 cent light. That future FEL will do so at ten or more times the IR upgrade's expected 10 kilowatts of average power — yet another future order of magnitude for the multiple stakeholders the program serves.

*Right:* Brian Holloway, William and Mary professor, with nanotube oven, a component that helps produce nanotubes with the FEL.

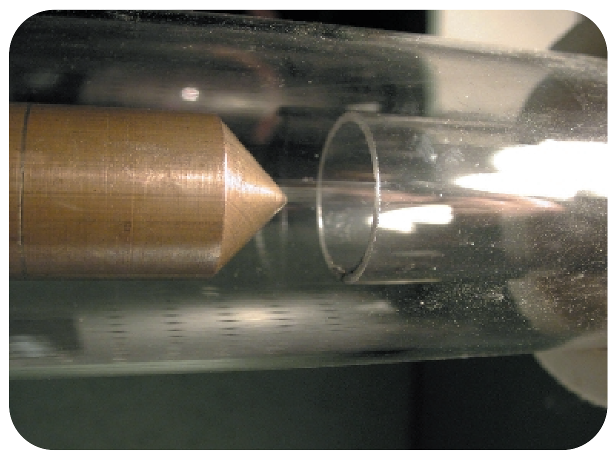


**Nanotubes** — rolled-up bits of carbon some 20,000 times thinner than a red blood cell — have been prominent in the news. They promise stronger composite materials, like those foreseen for building future airplanes. And they have properties such as high thermal conductivity and variable electrical conductivity that could prove useful in miniaturizing and otherwise improving electronics. Nanotubes might eventually lead to computers that operate a billion times faster than today's silicon-based machines.

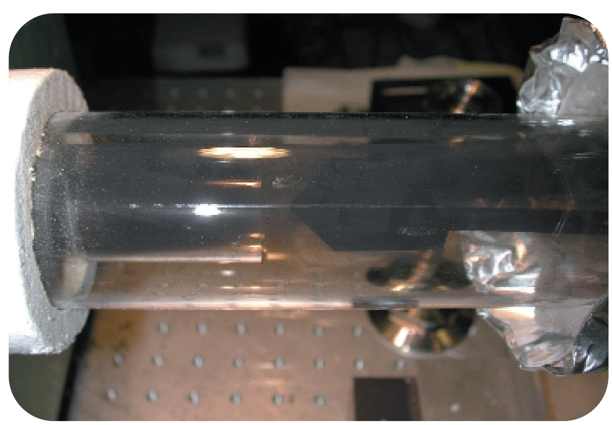
Because these molecular structures present a range of production challenges that might be circumvented or better understood by use of the Jefferson Lab Free-Electron Laser's repetition rate, wavelength tuning, and power, studies have been underway to find how the structures are formed, to determine the optimum conditions for making them with tailored properties, and to learn more about real-time process monitoring and control.

"They're a whole new class of material, smaller than the wavelength of light," says Brian Holloway of the College of William and Mary. He is working with Michael Smith from NASA-Langley and they use the Jefferson Lab FEL for nanotube experiments. "When we vaporize the surface of graphite, the carbon atoms rearrange themselves as nanotubes," he explains. "We're trying to understand that process."

Preliminary results from the FEL are promising. It has synthesized single-wall carbon nanotubes in bundles with smaller diameters than nanotubes produced by direct-current arc or by table-top pulsed laser vaporization (PLV) — and with production rates measured in milligrams per minute rather than milligrams per hour. Further FEL work is planned to understand and optimize PLV processes and to create unique materials, including silicon nanowires, germanium nanotubes, and gallium arsenide nanostructures.



(a)



(b)

(a) Cooled collector target for carbon nanotube production, before the laser is turned on.

(b) Collected, FEL-produced nanotubes.

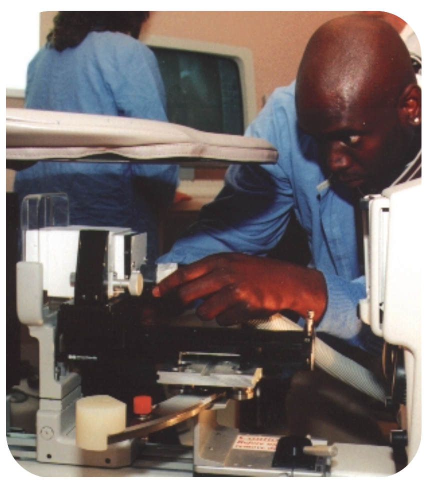
## ROLE OF TECHNOLOGY TRANSFER IN THE U.S. ECONOMY

Jefferson Lab's focus on basic nuclear physics research seems at first glance not to allow much room for applied science. But the unique technology needed to sustain electron-beam accelerator operation, and the equipment used by researchers to gather and interpret information on subatomic collisions, has engendered shorter-term applied benefits. Lab scientists and engineers have devised a number of devices that should find application well beyond the specialized fields responsible for their creation.

Technology transfer at JLab is focused in two primary areas. One is the development of sophisticated light sources, such as the Lab's Free-Electron Laser, that generate light to modify materials or for cutting and welding. The second is the development of detector technology for medical imaging, which may lead to a generation of highly sensitive, lightweight, portable medical-diagnostics devices.

"Technology transfer is not our main line of business," says Fred Dylla, JLab's Free-Electron Laser (FEL) program manager. "Given that, our rate of patenting is noteable. In the long run, the opportunities for tech transfer at the Lab will grow."

The Lab has thus far produced close to 115 patent disclosures. Of those, 72 were submitted for the patent-application process. Nearly 30 patents have been issued to date, including light-guide technologies, medical imagers, flaw-detection equipment, a fire-detection/prevention system, and a keyed, pluggable device that connects to a computer and allows access only to authorized users.



*Above:* Jefferson Lab instruments enable breast cancer detection.

The Lab has also received patents on specialized technologies unique to accelerator physics. Examples of these include valves, pumping systems, measurement devices for supercooled gases and liquids, specialized portals for microwave and radio-frequency energy transfer, leak detectors, and a device enhancing electron-beam focus.

"In the past we've concentrated on building a portfolio," says Rhonda Scales, assistant general counsel for the Southeastern Universities Research Association (SURA) and Jefferson Lab. Scales oversees and coordinates all aspects of the Lab's patent-application process. "Now we're paying more attention to the commercial value of the invention before we begin the patenting process. Some of the medical-imaging devices could eventually be worth millions. It's a matter of time before one of these pieces of technology achieves commercial success."

In addition to the potential of medical imagers, which hold the promise of rapid identification of the smallest cancerous tumors, Scales cites the promise of light-pipe technology, which derives from the sophisticated optical systems developed at the Lab. As the name implies, light can be channeled through the pipes, over great distance from natural or artificial sources, and without significant loss of illumination. The pipes can be used to brighten otherwise

US006271525B1

(12) **United States Patent**
**Majewski et al.**

(10) **Patent No.: US 6,271,525 B1**
(45) **Date of Patent: Aug. 7, 2001**

(54) **MINI GAMMA CAMERA, CAMERA SYSTEM AND METHOD OF USE**

(75) Inventors: **Stanislaw Majewski; Andrew G. Weisenberger**, both of Grafton; **Randolph F. Wojcik**, Yorktown, all of VA (US)

(73) Assignee: **Southeastern University Research Assn.**, Newport News, VA (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/159,177**

(22) Filed: **Sep. 23, 1998**

(51) **Int. Cl.**[7] ........................ **G01T 1/202**; G01T 1/208
(52) **U.S. Cl.** ........................ **250/367**; 250/368; 250/369
(58) **Field of Search** ........................ 250/363.1, 363.02, 250/367, 368, 369, 207, 214 VT

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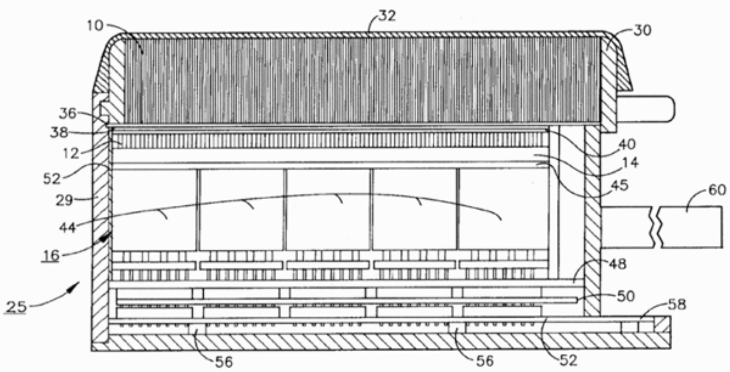
* cited by examiner

*Primary Examiner*—Georgia Epps
*Assistant Examiner*—Richard Hanig

(57) **ABSTRACT**

A gamma camera comprising essentially and in order from the front outer or gamma ray impinging surface: 1) a collimator, 2) a scintillator layer, 3) a light guide, 4) an array of position sensitive, high resolution photomultiplier tubes, and 5) printed circuitry for receipt of the output of the photomultipliers. There is also described, a system wherein the output supplied by the high resolution, position sensitive photomultipiler tubes is communicated to: a) a digitizer and b) a computer where it is processed using advanced image processing techniques and a specific algorithm to calculate the center of gravity of any abnormality observed during imaging, and c) optional image display and telecommunications ports.

**6 Claims, 4 Drawing Sheets**




inaccessible spaces, for agriculture, in structural-flaw detection, for external surgical illumination, and as decorative lighting or for machinery controls.

"Our main mission is basic research," Scales points out. "But technology transfer is very important. It helps to foster partnerships between industry and the government. And perhaps most importantly, tech transfer can have a great impact on the lives of ordinary citizens."

Before beginning work at the Lab all employees sign an intellectual property agreement that governs on-the-job invention and development of unique devices. Once an invention is submitted for the disclosure and patent process, it officially becomes SURA property. Nonetheless, the inventor stands to reap financial rewards if the invention proves a commercial success. Although inventors pay nothing out of pocket to underwrite the patent process, administrative costs are recouped from royalty payments. Once costs are covered, royalties are split 50-50 with the inventor.

*Left:* Jefferson Lab's patents in medical imaging continue to be of interest in the medical community.

## NEW BREAST CANCER IMAGING TECHNOLOGY

Each year in the U.S., 1.2 million women undergo biopsies to determine if suspicious findings in a mammogram may be breast cancer. While 900,000 of those biopsies are negative, every patient has had to endure the invasive and traumatic tissue-sampling procedure that has been the most accurate means of cancer detection — until now.

One of the new detection devices developed by the JLab Physics Detector Group in collaboration with Johns Hopkins University, the University of Virginia, George Washington University, and Dilon Technologies, Inc., is the Compact Scintimammography Gamma Camera. It is a small camera connected to a computer that uses scintimammography, a nuclear medicine method of breast tumor detection.

Scintimammography uses standard biological radiotracers (specially prepared chemicals carrying a gamma-ray emitting radioactive isotope that can mark certain biological processes) to locate a tumor. Research has shown that several types of cancer cells take up and accumulate these markers more readily than normal cells because they generally


*Left:* The Dilon 6800 incorporates several of Jefferson Lab's medical imaging patents to help detect breast lesions found on X-rays. This system, used in conjunction with a mammogram, could reduce the need for breast biopsies.

metabolize faster. In the past, scintimammography has been performed with standard full-sized clinical gamma cameras. The new compact detection device "senses" the gamma-rays the tumor emits after metabolizing the radiotracer and uses them to build an image of the tumor. This new detector can image the entire breast and capture close-ups of a tumor and provide higher resolution images than available previously.

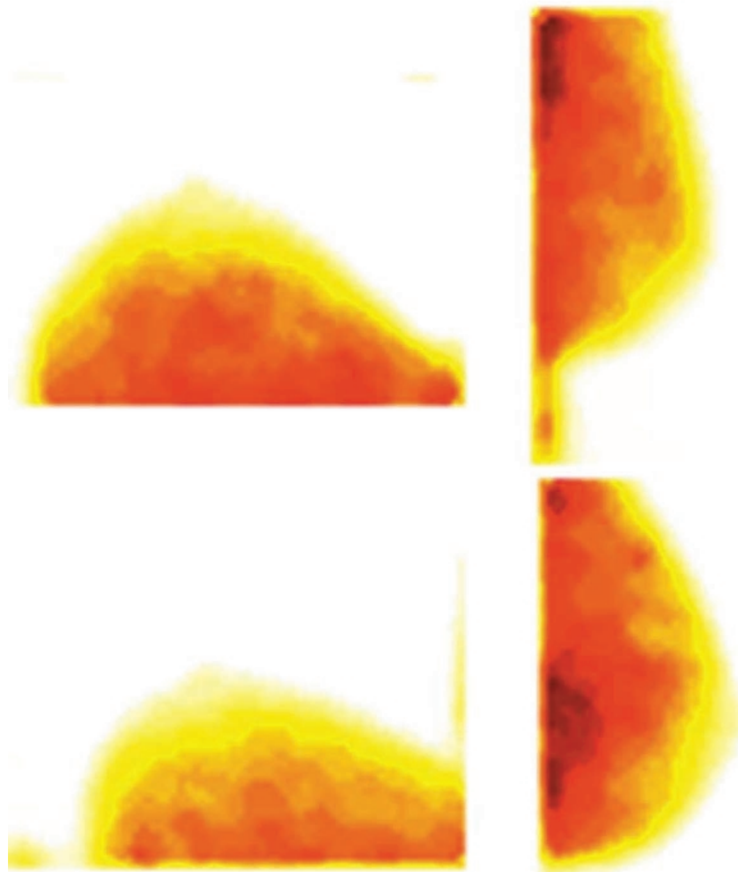
Scintimammography can also differentiate with high accuracy between benign and malignant tissue. The new compact camera developed by the Detector Group can be used to detect small tumors that would be difficult or impossible to read on a mammogram and with standard power resolution gamma cameras. This device is a direct spin-off of technology used in the nuclear physics mission of the Lab.

This new imaging method has undergone clinical trials at Johns Hopkins University, and additional clinical trials are underway at George Washington University Medical Center. Patients who already have been scheduled for breast biopsies are injected with a solution containing small amounts of the gamma-emitting radioactive isotope. The gamma camera detects the gamma rays emitted, and data acquisition and control software converts the camera images into digital signals that show up as bright spots ("hot spots") on the computer screen. Once this system has been proven, it also could potentially be used to measure the effectiveness of cancer treatments such as chemotherapy or used to detect other types of cancer, such as thyroid cancer.

Collaborating with Hampton University and Riverside Hospital, the local Newport News hospital, the Detector Group developed another "mini-gamma camera" to view a small region of the breast and constructed it to fit a commercial digital X-ray needle biopsy system. Using this device, researchers can obtain a digital X-ray image from the commercial system, which is then overlaid ("co-registered") with the gamma-ray image obtained with the scintimammography mini-gamma camera. This device is being used as a research tool to test the effectiveness of scintimammography to identify whether or not known lesions are cancerous.

As the mini-gamma camera detects lesions ("hot spots"), researchers simultaneously perform a digital X-ray mammogram in which potential tumors often show up as white masses. The information is transferred to the computer where the gamma imager software overlays the images from the gamma camera with those from the digital X-ray. If the two images line up, the tumor is likely to be cancerous.

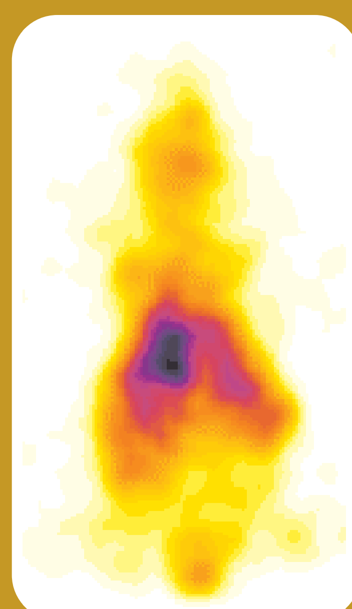
The digital X-ray reveals the internal structure of a potential tumor, while the scintimammography tells doctors how the tissue is functioning. To date, about 30 patients have been imaged with the device including some Jefferson Lab staff.



*Above:* Breast cancer images from actual clinical trials using the Dilon Technologies, Inc. device.

## A commitment to the future has the potential to help future generations.

At the Department of Energy's Thomas Jefferson National Accelerator Facility, new cutting-edge research for "Nuclear Imaging of Small Animals" has begun in collaboration with Oak Ridge National Laboratory and Johns Hopkins University. The goal of the collaboration is the development of instrumentation that will allow bio-medical researchers to study mice with nuclear medicine imaging techniques while the mouse is awake and unrestrained. The novel technology should offer scientists the opportunity to use conscious mice to study neural processes in real time and over an extended period of time.



# COMMUNITY OUTREACH

### K-12 Education

In partnership with the local school divisions and the surrounding community, Jefferson Lab is dedicated to:

- explaining math and science to students, teachers, parents, and the general public through Lab events and community partnerships;
- providing Jefferson Lab-related resources for teachers and faculty; and
- providing a nurturing research environment for college students and teachers.

Jefferson Lab uses staff scientists and engineers to achieve these goals. During FY 2001, about 10,500 students and 750 teachers interacted with Jefferson Lab staff who shared their knowledge, experience, and enthusiasm.

The BEAMS — Becoming Enthusiastic About Math and Science — program brings classes of sixth, seventh, and eighth grade school students with their teachers to the Lab for interactions with staff via science and math activities. BEAMS targets the middle schools in Newport News with the largest at-risk student populations. Through the BEAMS program, Jefferson Lab motivates students to continue learning, provides teachers with activities based on the science and technology at Jefferson Lab, and affords parents the opportunity to become involved with their children's education during BEAMS Family Night, while providing Jefferson Lab staff a means to share their experiences, expertise, and enthusiasm.

***Results from the on-going evaluation of BEAMS show that students attending BEAMS are significantly more positive about science and school than students not attending.***

Results from the on-going evaluation of BEAMS show that students attending BEAMS are significantly more positive about science and school than students not attending. Teachers are reporting that BEAMS increases their awareness of hands-on science, applications of math and science, and careers in math and science. And finally, parents report the BEAMS program is a unique positive influence on their children. Preliminary results from Virginia standardized test scores show that BEAMS is helping to close the gap between traditionally low scoring schools and average scoring schools. Huntington Middle School, where students attend BEAMS in grades 6, 7, and 8, showed improvements in test scores from 1998 to 2000 of 23 points in mathematics and 21 points in science. Huntington Middle School's parent school division showed increases of 15

*Left:* Al Guerra shows how an electromagnet works to a group of young students.


*Right:* Phil Adderley, a regular BEAMS volunteer, explains the concept of probing the shape of an object even if you can't directly "see" the object.

points in mathematics and 13 points in science.

Other community-based partnerships sponsored by JLab include:

- the Physics Enrichment for Science Teachers mini-science course for middle school teachers, taught by Lab staff, former teacher researchers, and special guests;
- participation in the DOE's Energy Research Undergraduate Laboratory Fellowship (ERULF) program, a ten-week summer fellowship at Jefferson Lab for undergraduate physics majors;
- the Jefferson Lab Science Series showcasing diverse scientific fields and topics;
- Cooperating Hampton Roads Organizations for Minorities in Engineering (CHROME), which sponsors school-based science and math clubs throughout southeast Virginia;
- summer research internships for high school students; and
- materials and information distributed to precollege teachers through teacher development workshops and visits to Jefferson Lab for classes of students.

### Public Outreach

A variety of methods are used to maintain positive communication with the public, an important element of the Lab's community relations program.

Lab personnel visit and host local civic organizations by serving as guest speakers on JLab-related topics as well as conducting tours of the Lab.

A new concept launched this year is a popular science book, author lecture series. For example, Frank Close, a high-energy physicist with a newly published book, *Lucifer's Legacy*, lectured on the topic of super symmetry and then signed books for the science-minded public who attended. This attempt forged a partnership with the local Barnes and Noble book retailer who brings the books to the Lab for the lecture. Both parties are working together to attract additional science writers to the area over the coming years and have many ideas for authors.

Jefferson Lab hosted its biennial Open House for the public in 2001 with great success. Each open house exceeds the Lab's estimate for public attendance and interest in the science conducted here. On alternating years the Lab staffs an educational booth in the high technology building at the Virginia State Fair, and reaches as many as 300,000 attendees during a two-week period.

### Huntington Middle School 8th Grade Scores

| | Math Scores '98 - '99 - '00 | Science Scores '98 - '99 - '00 |
|---|---|---|
| Huntington Middle School (BEAMS School) | 25 – 49 – 48 (+23) | 46 – 64 – 67 (+21) |
| Newport News School Division (Includes Huntington) | 44 – 59 – 59 (+15) | 66 – 75 – 79 (+13) |

# ADMINISTRATIVE HIGHLIGHTS

## CRITICAL POSITIONS

As a mature physics research laboratory moving into areas of growth, staffing is critical to maintaining momentum in on-going programs and ensuring success with new programs being developed.

In November, 2000 Jefferson Lab's Director, Hermann Grunder, announced that DOE had selected him as the next Director of Argonne National Lab. Grunder had been Jefferson Lab's director since 1985. Under his leadership, the Lab was completed on cost and on schedule and began operations in 1994. He was instrumental in leveraging the Lab's resources to benefit the local community, in the form of educational outreach programs and economic development initiatives.

SURA announced Christoph Leemann as JLab's new Director on November 16, 2001. Leemann joined the Lab (then called the Continuous Electron Beam Accelerator Facility) in 1985 as Associate Director of the then Accelerator Physics Division, where he was responsible for beam dynamics and overall accelerator design. In April 2000, Grunder appointed Leemann as the Lab's first Deputy Director. In that capacity he oversaw day-to-day operations of the Lab and strengthened the role of the Director's Office in internal Lab matters. His priorities included increased attention to physics research — particularly as crucial Long Range Plan activities took off, achieving high quality and funded FEL user programs, success of the Spallation Neutron Source, and development of key core competencies. Then in November 2000 he was asked to serve in Interim Director when Grunder moved to Argonne National Lab.

After a long search, Jefferson Lab hired Gwyn Williams as the FEL Basic Research Program Manager. Williams is developing a research program for the FEL and a funding plan to pursue and develop those projects. His focus is to nurture a basic research program while balancing that program with the FEL's applied programs. Prior to joining Jefferson Lab, Williams ran six light-source laboratories at Brookhaven National Lab.

The Lab brought Warren Funk on board as Jefferson Lab's Project Services Manager in support of DOE's Spallation Neutron Source. His primary responsibilities are to provide cost analysis and scheduling support to Claus Rode, JLab's SNS Project Manager. Jefferson Lab is one of six DOE national laboratories contributing to the development and construction of the $1.4 billion Spallation Neutron Source in Oak Ridge, Tenn.

Another vital hire is John "Rusty" Sprouse, Jefferson Lab's Plant Engineering Director. His department is responsible for supporting the Lab's mission and the scientists who use JLab by managing the site's everyday activities such as site-wide security, property inventory and grounds maintenance. The department also manages plans, designs and construction of new buildings as well as additions and modifications to existing spaces.

A new Human Resources and Services Director has joined the staff. Kelly Caccetta brings to the Lab her experience as the Human Resources Manager at Gateway, Inc., where she was responsible for employee and labor relations, recruiting, compensation and benefits, and occupational health and safety.

At the end of 2000, Christoph Leemann announced the hiring of Swapan Chattopadhyay as the Lab's new Associate Director for Accelerators. Chattopadhyay joined the Lab's staff early in 2001. He came to Jefferson Lab from Berkeley Lab, where he had served as the Director of the Center for Beam Physics since December 1991.

# ADVISORY BOARDS AND REVIEWS

*How does the government get the best performance from an institution? In the case of the management and operating contract held by SURA for the operation of Jefferson Lab, DOE instituted a performance-based contract where mutually agreed-to metrics are tracked, measured and reported. The results of these metrics are summarized below.*

## Administrative Peer Review

Jefferson Lab's first review of the year came in February when the Administrative Peer Review convened at the Lab. The panel included senior administrators from other DOE Labs, the local business community, and DOE staff from the regional Oak Ridge Office (ORO). The review assessed the performance of the Administration Division over the previous year. Jefferson Lab received the highest rating ever for performance in many key areas, and panel members commended the Administration Division for the job it was doing in support of the physics mission at Jefferson Lab.

## Science and Technology Review

Lab leadership and staff earned compliments and high praise during its Science and Technology Review in September. The annual review evaluates the quality, performance and significance of Jefferson Lab's major activities, in the context of the Nuclear Science Advisory Committee's (NSAC) Long Range Plan and the national nuclear physics program. It is an important part of the Lab's performance-based contract.

Committee members described Jefferson Lab as a well-managed institution and a first-class operation with a vigorous science program. Many positive comments were made about the dedicated staff, satisfied users, accelerator operation, polarized beam and the high caliber science and unprecedented data coming from experiments. In addition, the group had high praise for the Free-Electron Laser's (FEL) performance and its match with the Lab's core technologies and encouraged the development of the FEL's basic research program.

## Institutional Management Review

In early November, the Lab completed its biennial Institutional Management Review with flying colors. The Lab rated "outstanding" in nearly every area.

The review is conducted to evaluate the management and operation of the Lab, as part of the performance-based contract between the DOE and the Southeastern Universities Research Association (SURA). The review assessed the Lab's strategic planning, managerial effectiveness and organizational culture. According to the report sent to SURA President Jerry Draayer by the review committee's chair, "The Lab's performance with respect to strategic planning exceeded expectations (rated outstanding), managerial effectiveness exceeded expectations (rated outstanding), and organizational culture greatly exceeded expectations (rated high outstanding)." The Lab's overall performance rating was judged to be "outstanding."

Although this is just one of several reviews conducted in accordance with the Jefferson Lab contract, both DOE and SURA view this assessment with particular importance as an evaluation of the overall effectiveness of Laboratory leadership and management.

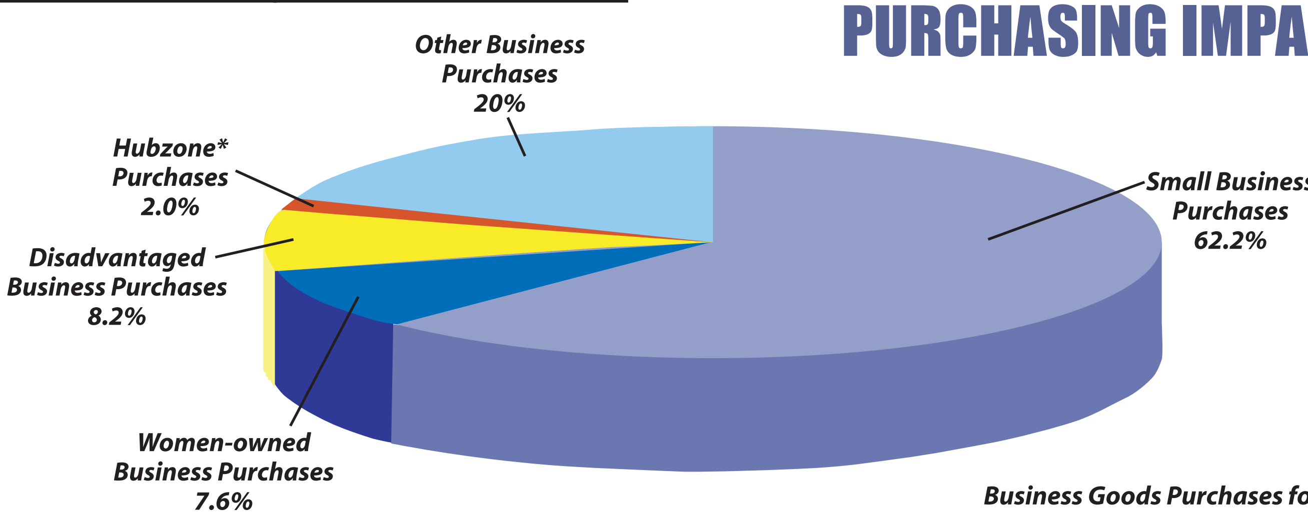
In the area of strategic planning, the committee applauded the Lab's production of scientific results and its current world leadership in experimental capabilities in its energy range, as well as in superconducting radiofrequency technology. Under managerial effectiveness, the Lab was complimented for its efficient and effective use of resources to enhance scientific outcomes at the Lab. Specifically cited were the Lab's "superb" attention to environmental safety and health, and the "excellent process and utilization goals to sustain performance." The Lab's organizational culture rated a high outstanding by the review team, and was described as "stand[ing] out among its DOE peers for its sense of community, both internal and external. …[S]taff members identify with the Lab and its mission and have pride in contributing to its success. There is broad appreciation of the benefits of having a diverse staff. …Perhaps the most concrete manifestation of the superb organizational culture is the extensive volunteer work that the staff performs in the local community, particularly with respect to K–12 education."

## Annual DOE Rating

At year's end, the DOE rated Jefferson Lab "outstanding" in all major evaluation categories under SURA's performance-based contract. The evaluation incorporates results of the Lab's self-assessment, as well as DOE appraisals, observations, and outside reviews of the Lab. This marked the third year in which the Lab received outstanding ratings in all seven areas of responsibility: science and technology, reliable operations, science and technical manpower, corporate citizenship, EH&S, business practices, and institutional management.

# JEFFERSON LAB PURCHASING IMPACT

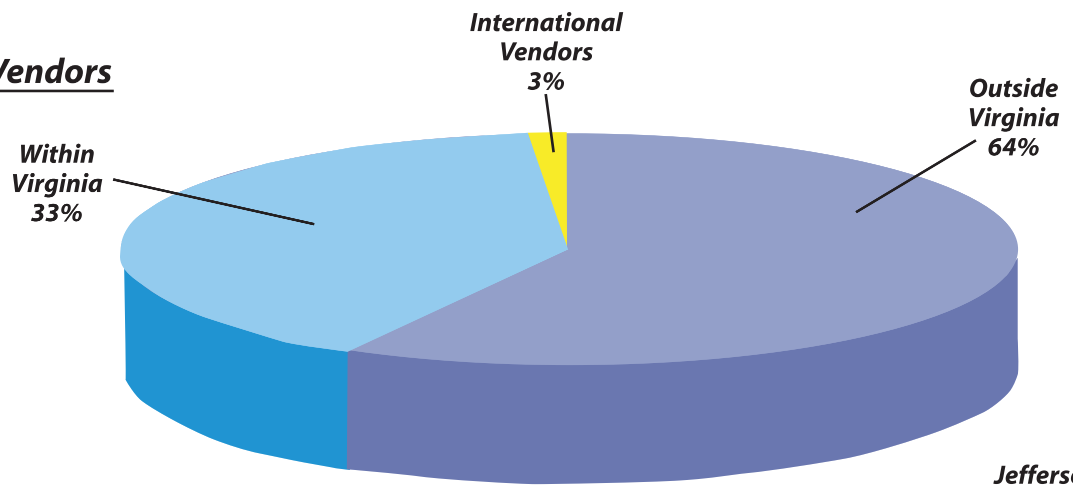
## Small and Disadvantaged Business Purchases




**Business Goods Purchases for the fiscal year totaled $34.9M**

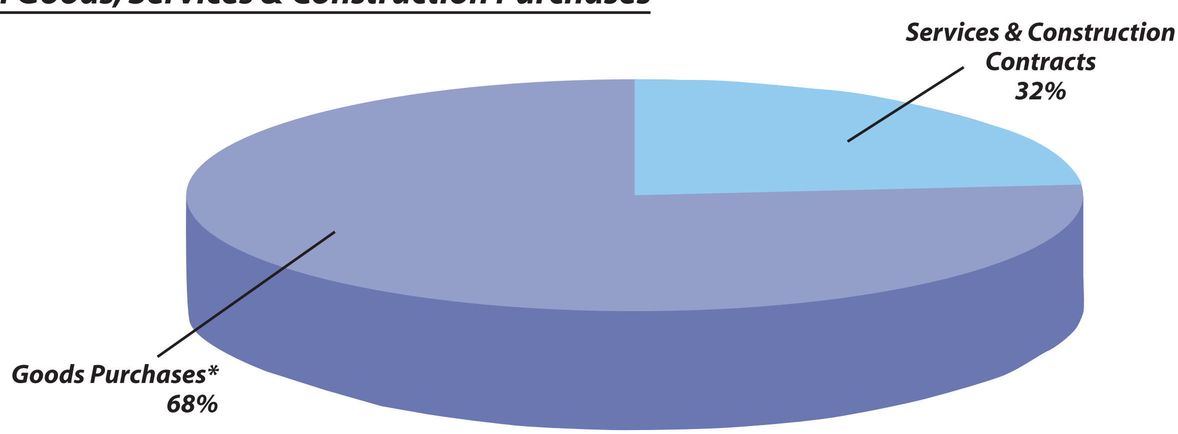
*Small businesses listed as qualified HUBZONE businesses, by the Small Business Administration.

## Jefferson Lab Vendors




**Jefferson Lab uses approximately 1000 vendors**

## Total Goods, Services & Construction Purchases




**Goods, Services and Construction Purchase Costs for the fiscal year totaled $42.7M.**

* 4% of all Goods Purchases were made via E-commerce and 25% were made via government credit card.

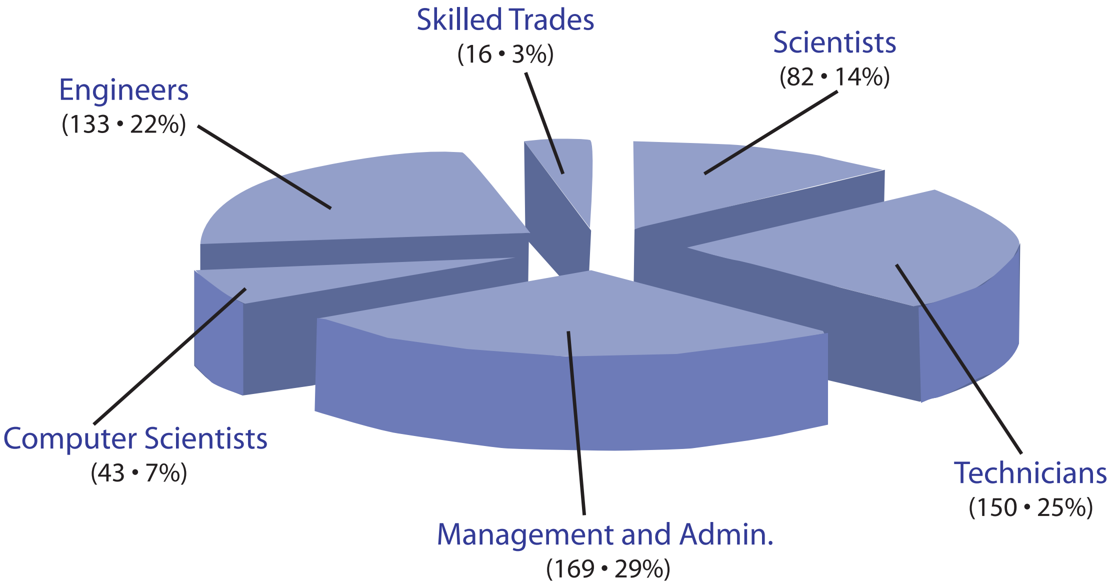
# FUNDING AND STAFFING

## Funding

| | FY2000 M$ | FY2001 M$ |
|---|---|---|
| **DOE Office of Science** | | |
| Nuclear Physics | 73.3 | 74.1 |
| Basic Energy Sciences | 11.8 | 22.4 |
| Measurement Science | 0.2 | 0.6 |
| Other | 0.2 | 0.1 |
| **DOE Miscellaneous** | | |
| Accel Prod of Tritium | 0.4 | — |
| Safeguards and Security | — | 0.6 |
| Cyber Security | — | 0.3 |
| Energy Management | — | 0.5 |
| Work for Others | 0.9 | 0.1 |
| Free Electron Laser | 9.0 | 7.6 |
| Commonwealth of VA | 1.4 | 1.4 |
| **Total Laboratory Funding** | **97.2** | **107.7** |

## Staffing

TOTAL 593



# IN MEMORIAM

Nathan Isgur died July 24, 2001, after a long and valiant battle with multiple myeloma, a rare cancer of the bone marrow. The international nuclear physics community lost a highly regarded member; and Jefferson Lab lost its Chief Scientist and Senior Theorist.

Born in South Houston, Texas, on May 25, 1947, Nathan was raised and educated in South Houston. In the fall of 1964 he entered the California Institute of Technology in Pasadena, where he earned his Bachelor of Science degree in physics in 1968. Nathan went to the University of Toronto for his Ph.D., which he obtained in 1974, and was appointed a member of the Toronto faculty in 1976. He was a superb teacher and lecturer and many of his undergraduate and graduate students have faculty positions at U.S. and Canadian universities.

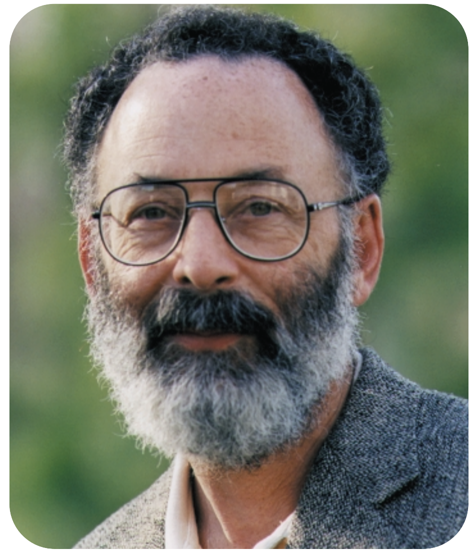
While at Toronto he collaborated with Gabriel Karl of the University of Guelph on the physics of baryons in the quark model. The (Quantum Chromodynamics) QCD-improved quark model for baryons was very successful and is still the benchmark for baryons.

On various leaves at Oxford, Nathan collaborated with Jack Paton, on flux-tube models for gluons in hadrons. Their model made predictions for new excited hadrons involving gluonic excitation; investigating these predictions is a major motivation for Jefferson Lab's proposed Hall D experimental program. In another notable collaboration with Chris Llewellyn Smith, the applicability of perturbative QCD to exclusive processes was discussed.

Nathan's most celebrated work was with Mark Wise, a former undergraduate student who is now at Caltech. They studied semi-leptonic decays of heavy mesons, with charm or beauty quarks; this led to the discovery of heavy quark symmetry in QCD. This symmetry, which becomes exact in the limit of infinite quark mass, allows an economical description of many heavy meson decays. Two of their seminal papers each have more than a thousand citations on the SPIRES database at SLAC, and appear on Stanford's international list of "all-time top-cited high-energy physics articles." Their discovery also led to the award of the American Physical Society's J.J. Sakurai Prize in the spring of 2001 to Isgur, Wise, and Voloshin.

In 1990, Nathan moved from Toronto to Jefferson Lab to assume leadership of the Theory Group. He was attracted both by the opportunity to build a new theory group, and to play a role in guiding the experimental program of the new facility. Simultaneous with his appointment at the Lab, he joined the faculty at the College of William and Mary and was honored as a Governor's Distinguished CEBAF Professor.

At Jefferson Lab, Nathan initiated a program to strengthen ties with the local and regional nuclear physics groups. Through joint appointments with local universities, he doubled the number of positions in the Theory Group; following this success, the Lab extended the approach to joint experimental appointments. Nathan also instituted a program of bridged positions, which allowed universities to recruit bright young nuclear physicists for positions a few years before the incumbents retired. These programs resulted in more than 60 new nuclear physics faculty positions in the southeastern U.S. He devoted a great deal of effort to these programs and was very pleased when they were imitated elsewhere.



**Nathan Isgur**
1947-2001
Jefferson Lab Senior Theorist
Chief Scientist and Theory Group Leader

Nathan was very effective at expressing new physics ideas in simple terms. This ability, as well as his skill in creating enthusiasm for physics within the non-technical audience, was a great asset in discussions with policy makers and funders. In recognition of his contributions, he was appointed Chief Scientist of the Lab in 1996.

When Nathan was diagnosed with his illness, he started to publish at an accelerated rate. He published some 10 papers in refereed journals over the last four years, and left about seven preprints in the process of publication. During his last two years at the Lab, Nathan established a collaborative Lattice QCD effort with MIT. This involved the addition of two new staff members to the Theory Group as well as substantial prototype computing hardware. He was committed to the Lab's 12 GeV upgrade project and the proposal for a new experimental facility (Hall D) to search for exotic states involving gluonic excitation.

Thomas Jefferson National Accelerator Facility

12000 Jefferson Avenue
Newport News, VA 23606
www.jlab.org • 757.269.7100